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A Comparison of Climate Parameters at an Open Site and Within an I45/51 Hybrid Poplar Plantation

by

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Abstract

Compared to open areas, which are typical of most climate stations, few observations of climate data are available within forest environments and particularly within hybrid poplar plantations. Microclimates within such farmed forests differ significantly from those of open areas. Well documented field experiments are required to assess the farmed forest microclimates and compare them with those of open areas.

Measurements of climatological parameters including solar radiation, air temperature, soil temperature, precipitation, relative humidity, and wind speed and direction were made during the 1982 and 1983 growing seasons within an I45/51 hybrid poplar plantation and at an adjacent open field site in Eastern Ontario. On the basis of the amount of solar radiation received at the open site, days were classified as clear, partly cloudy, or overcast. Climatic parameters were analyzed taking into account sky conditions and synoptic weather patterns. Comparisons of climate parameters were made between the open and plantation sites and also with neighboring climate stations where data were available.

The results are presented in tabular or graphic form along with methodology, comments, and suggestions for future studies.

Sommaire

En comparaison avec l'environnement forestier, particulièrement la plantation de peupliers hybrides étudiée, l'environnement d'une station climatologique typique en zone dégagée est sujet à plus d'observations climatiques. Le microclimat d'une forêt agricole est bien different de celui d'une zone dégagée; des études sur le terrain solidement documentées sont necessaires pour évaluer le microclimat d'une forêt agricole et le comparer à celui de zones dégagées.

Pendant les saisons de croissance de 1982 et 1983, on a mesuré des paramètres climatologiques tels que le rayonnement solaire, le température de l'air et du sol, les précipitations, l'humidité relative, et la vitesse et la direction du vent dans une plantation de peupliers I45/51 hybrides ainsi que dans une zone dégagée voisine dans l'est de l'Ontario. Selon le rayonnement solaire reçu sur la zone dégagée, on a classe les jours en differente categories : "clair, partiellement nuageux, et couvert". On a analysé les paramètres par rapport a la nebulosité et aux configurations météorologiques synoptiques. On a effectué des comparaisons de ces paramètres, entre la plantation et la zone dégagée et, aussi avec ceux de stations climatologiques proches ayant des données disponables.

Les resultats, présentés sous forme de tableaux et de graphiques, sont accompagnés de la methodologie utilisée ainsi que des commentaires, et des propositions sur de futures études.

A Comparison of Climate Parameters at an Open Site And Within an I45 / 51 Hybrid Poplar Plantation

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Introduction

The forestry and agricultural needs for weather and climate information often vary significantly from those of other traditional users such as the aviation industry or urban interests. Plant growth and development is directly related to climate parameters such as solar and net radiation, air temperatures, soil temperatures, air humidity, precipitation and wind speed and direction. These parameters can differ considerably over relatively small distances because of changes in topography, vegetation or other microclimatic factors. Observations of climate parameters within forested areas have been very sparse and within the farmed forest environment even more limited. On the other hand, at airports and to a lesser degree at stations that are operated by agricultural agencies and institutions, many more meteorological data are available. Precipitation and temperature observations by volunteer observers are collected on a daily basis over a large part of the country, however, these observations are usually concentrated in populated areas. Meteorological instruments at most of the above sites are deliberately positioned and located so as not to be effected by microclimatic or topographic influences. They are as much as possible located on level ground out of the effect of tall vegetation, buildings or other obstructions which could in any way alter the local meteorological observations. In this paper we shall compare observations taken in an open site, typical of the normal locations as described above, to those taken within a poplar plantation which is more representative of a farmed forest environment.

There are some spatial and temporal limitations to this study. Most of the observations were taken between mid-July and the Thanksgiving weekend in October 1982. At the open site and the site in the I45/51 hybrid poplar plantation, which from this point in the text will be referred to as the bush site, solar radiation, soil temperatures, and precipitation were measured until the end of October, 1983. Disruptions in this period of record did occur however, as a result of operational field and forest activities; datalogger and/or sensor failure. Forestry and agricultural operations such as spraying necessitated temporary suspensions in the observing program or temporary removal of particular sensors. Power supply difficulties and disruptions also contributed to the loss of data. Charts, graphs and tables in this paper which compare data from the open and bush sites use only observations of parameters from days when measurements of radiation and the elements under comparison were complete at both sites. Leaf area does have a significant influence on climate parameters in forest and plantation environments; however, for the period when most of the observations were taken, the trees remained in leaf. Thus, the influence of leaf area will not be considered in detail in this paper.

In spite of these limitations valuable information has been gained on the micrometeorology of a farmed forest. Methodology has been developed which can be used for more intensive study over longer periods and at other locations.

The microclimate of forests and microclimate in general have been examined by a number of authors; however, there have been few statistical studies particularly relevant to the Canadian environment. Rudolf Geiger in his text book on microclimatology, The Climate Near The Ground (1966) gives examples and cites case studies in Germany and elsewhere in Europe by authors such as A. Baumgartner. The text considered topics such as the measurement of light in the forest, temperature, humidity, and wind characteristics as well as the influence of leaf area. In Canada, H.J. Johnson, et. al. (1971) undertook a literature review regarding the implications of large-scale clearcutting in Alberta. This paper, though directly related to a specific problem in Northern Alberta, describes many of the microclimatological factors particularly as they exist at the edge of forested areas. The authors reviewed findings of others such as Kittredge (1962) who studied forest soil temperatures and Jemison who investigated July and August weather and fuel moisture for three years on three sites at the Priest River Forest Experiment Station in Idaho, U.S.A. in the early 1930's. Jemison (1934) considered maximum air temperatures, soil temperatures, surface duff temperatures, relative humidity, absolute humidity, wind movement, evaporation rates, duff moisture, and branchwood moisture in full-timbered, half-cut and clear-cut areas. Jemison concluded from his study that the more open the forested area is the higher is the maximum air temperature and that soil and duff reach higher temperatures in open areas than more closed areas. The above conditions within the open site would result from more short-wave solar radiation being received and absorbed at the surface and more long-wave radiation from the surrounding vegetation. Minimum air temperatures are higher in timbered closed areas when compared to more open sites as a result of terrestrial longwave radiation being reflected back toward the earth at night by the forest canopy. During the day the forest canopy absorbs or reflects some of the incoming solar radiation before it can reach the surface. In the case of more open sites, the terrestrial radiation from the surface escapes directly into the atmosphere since there is no intercepting canopy. Absolute humidity tends to remain higher in wooded areas than in open areas. Absolute moisture levels within the closed, forested areas are higher and evaporation from the surface is lower. The combination of higher absolute humidity and lower temperatures leads to relative humidity values within the closed forested areas that are higher than at more open sites. Wind speed is usually reduced in forested areas as compared to open areas. Kittredge (1962) reports that on an annual basis velocities in a forest are usually 20 to 50 percent of those in the open. Velocities also can vary with height and can be directly related to canopy structure and stand architecture in general. For example, wind direction and speed can be altered by the alignment and spacing of rows of trees in a plantation.

The results of the above modifications to the microclimatic parameters are a significant alteration in the magnitude and direction of the energy flux within the forest. During the day lower temperatures and wind speeds

reduce evaporation below the canopy and therefore humidity remains relatively constant. Also the active evapotranspiration surface in forested environments is augmented by the upper positions of the canopy because leaf area which is exposed to moving air and solar radiation is increased.

There is some evidence that more moisture is received below the canopy than in the open due to foliage interception and subsequent stemflow and dropping. In small open areas snow tends to accumulate. Johnson et al. (1971) concluded that the influence of the forest on most climatic parameters rarely extends more than two or three times the height of the trees away from the clearcut or forest edge.

Topographic differences can also have an effect on the microclimate of a site. In addition to the sheltering effect of topographical obstruction (e.g. blocking or steering of air away or towards a particular area), topographic relief can dramatically alter the temperature regime of an area. For example, E.I. Mukammal (1977) examined temperature inversions and air drainage in the Niagara region and R.A. Treidl, et.al. (1978) investigated air drainage and inversions within an orchard in southwestern Ontario during the spring months. The land forms and general location of these studies were similar to those of the present study. The authors concluded that open areas with light winds are very susceptible to radiational cooling and the formation of inversions. Cold air which is heavier than warmer air tends to flow down slopes and pool in low lying areas. This process is increased when light winds aid in this downward movement. Trees at the base of a hill tend to slow down this movement and contribute to the accumulation of pockets of cold air. Recent work in the Kananaskis area of Alberta also confirms this valley influence.

Location:

The study site was located within the Ontario Ministry of Natural Resources fish hatchery property at Codrington, Ontario (77°42'W and 44°08'N). The hatchery is approximately 16 km north of Lake Ontario. The Codrington site consists of a moraine, approximately 160 metres in elevation to the south; located at the base of the north-facing slope was an eight-year old I45-51 poplar plantation covering 2.23 hectares with an open field to the north. The trees were approximately 15 metres high during the study period in 1982 and 1983. In March 1984, the plantation was harvested and copice regeneration was allowed to take place. This effectively terminated the project at Codrington. The field north of the plantation has an average elevation of 130 metres. During the study period this field was leased to a farmer who planted it in soybeans. Photo 1 is an air photograph of the Codrington property as it appeared in October 1982. The vantage point is from the south looking north.

The area surrounding Codrington is typified by rolling terrain that is characteristically glacial in origin as exemplified by the presence of moraines and drumlins. Most of the land surrounding the study site is under agricultural use (dairy and field crops), but some is forested either as natural mixed forest or as red pine plantation. Photo 2 illustrates the

Photo 1. An aerial view of the Codrington Property, October, 1982.

Photo 2. Land use and topography of the Codrington area.

local topography and land uses. Figure 1 shows the geographical location of the Codrington site in South-central Ontario. Figure 2 is a sketch of the study site showing the location of the instrumentation. The Codrington property was made available for the study by the Ontario Ministry of Natural Resources which in a cooperative effort with Environment Canada was investigating the climatic sensitivity of farmed forests for renewable energy sources. Due to lack of further funding and the earlier than anticipated harvesting of the plantation the study was terminated.

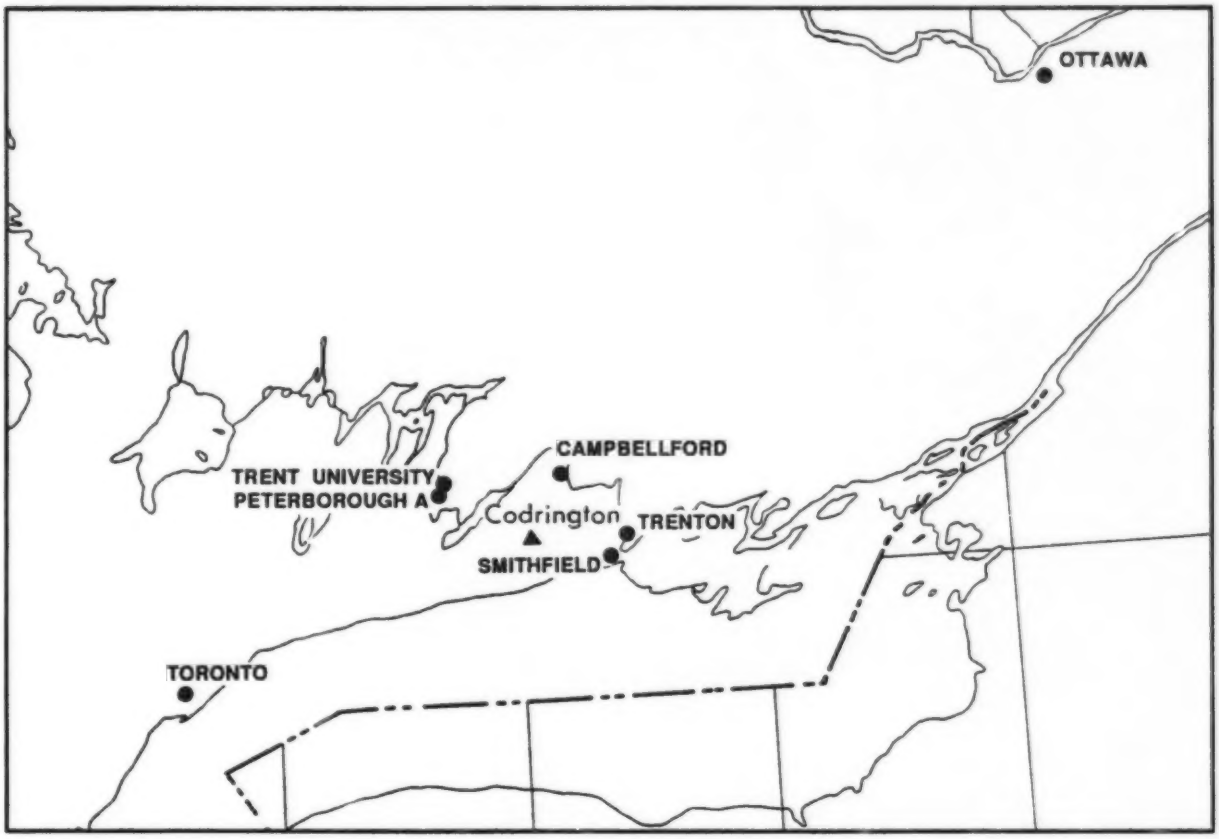


Figure 1. The Codrington Site and neighboring climatological stations in Ontario.

Instrumentation and Site Description:

On the Codrington property three sites were instrumented for the study. One was atop the moraine at the south end (hill site). The second was placed in the centre of the poplar plantation to the north of the hill site. Approximately 500 metres to the north of the plantation the third site (open site) was located in an open field. At each of the above places a tower was erected. Those at the hill and open sites were 10 metres high whereas at the bush site a 15 metres tower was erected to clear branches of the plantation canopy. Photographs 3, 4, and 5 illustrate the towers and anemometer equipment exposures at the three sites. On each tower was mounted a Campbell Scientific CR21 datalogger with an interface to a tape recorder in order to

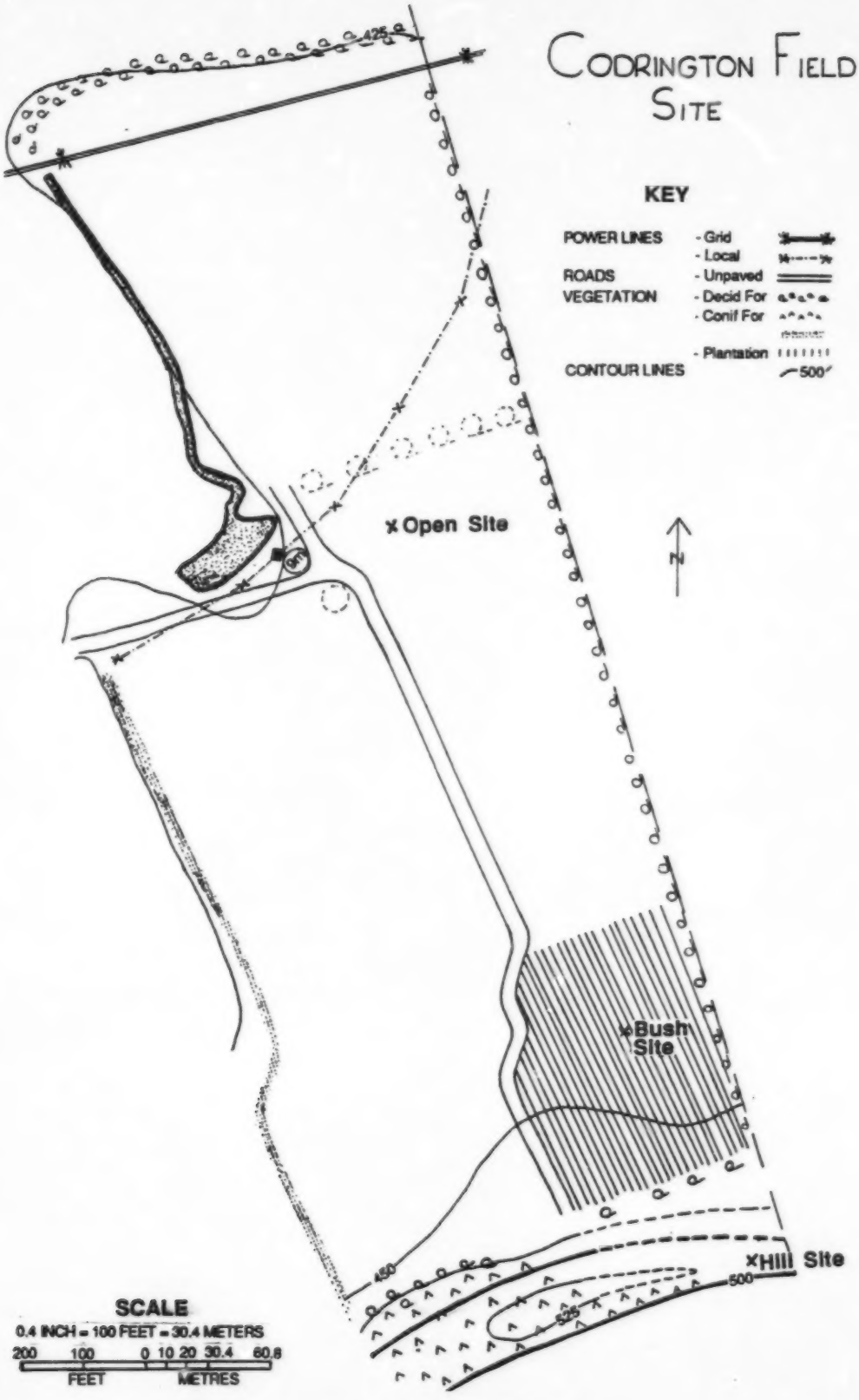


Figure 2. Codrington Field Site.

store climatic observations. At the top of each tower was mounted a MET-ONE model 023 wind direction vane and rotating cup wind speed sensor. Voltage measurements from these sensors were converted to wind directions in degrees or pulse counts into wind speeds in metres per second by the dataloggers. Also at each site temperatures were measured at the 1.2 metre level with a thermistor (Campbell Scientific Model 101). A Campbell Scientific Model 201 probe which measures temperature and relative humidity was also located at this level. The model 201 relative humidity probe contains a Phys-Chemical Research model PCRC-11 +/- 1% deviation RH sensor and a Fenwall UTT-51J1 thermistor. All measurements were converted to metric units by the dataloggers. At the bush and open sites air temperatures near the surface and soil temperatures at 10 centimetres below the surface were also measured with a model 101 thermistor. Solar radiation was measured at the bush and open sites by Epply Pyranometers mounted at 1.6 metres and connected to the dataloggers. Precipitation was measured during the summer months using tipping bucket raingauges connected to the dataloggers at the open and bush sites. During the winter months Belfort volumetric precipitation gauges were used to record daily precipitation amounts. After the Thanksgiving weekend in October, 1982 all instrumentation was removed from the hill site. The anemometers, humidity and air temperature probes were also removed from the bush site. (This equipment had been on loan and was required for other projects.) Data were initially stored by the dataloggers in buffers then transferred to cassette tapes which could be returned to the Climate Center and dumped onto the in house AS9060 computer where data quality could be checked and further statistical analyses performed. Photographs 6 and 7 show the instrumentation nearer to the ground at the open and bush sites.

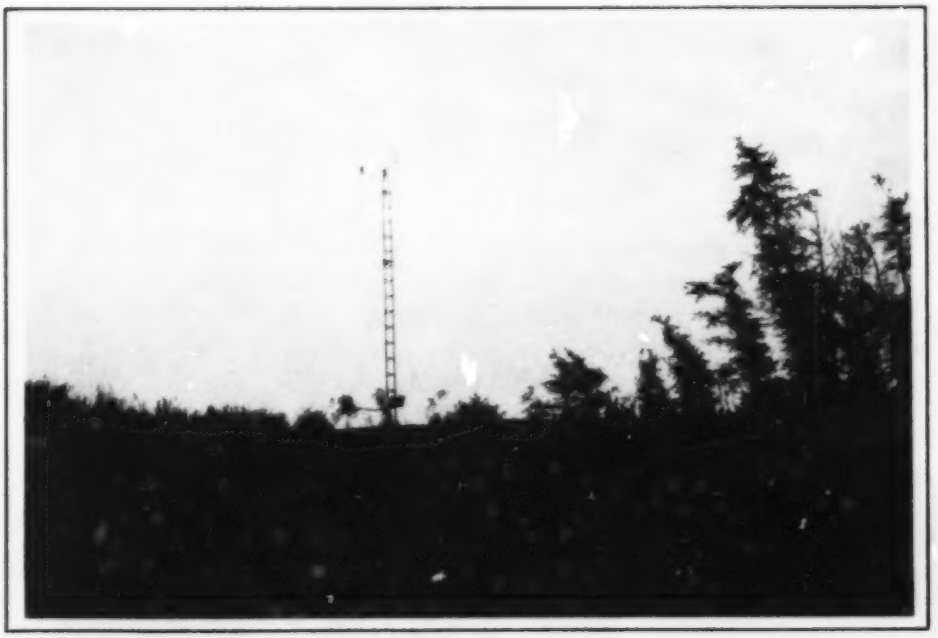


Photo 3. The "hill site" tower.

Photo 4.
The "open site" tower.

Photo 5. The "bush site" tower.

Photo 6. Open site instrumentation near bottom of the tower. To the right (south side) are mounted the Epply Pyranometer resembling a light bulb and the net pyranometer. Temperature and humidity sensors and the CR-21 datalogger are mounted to the left. The tipping bucket raingauge is located in the foreground.

Photo 7. Bush site instrumentation near bottom of the tower. To the left (south side) is mounted the Epply pyranometer. To the right from top down are the CR-21 datalogger, the model 201 temperature and relative humidity sensor mounted at 1.2 m and a model 101 temperature sensor near the ground. The rain gauge is behind the photographer.

DATES OF PARAMETER OBSERVATIONS

PERIOD OF OBSERVATION

Parameter	Element Code	Height Metres	Hill Site	Bush Site	Open Site
Air Temperature (°C) (101) Sensor	078	1.2	07/15/82-10/11/82	07/15/82-10/11/82	07/15/82-11/08/83
Sfc. Temperature (°C) (101) Sensor	078	0.0		07/15/82-10/11/82	07/15/82-11/08/83
Soil Temperature(°C) (101) Sensor	078	-0.1		06/01/83-08/31/83	07/15/82-11/08/83
Relative Humidity (%) (201) Sensor	080	1.2	07/15/82-10/11/82	07/15/82-10/11/82	07/15/82-11/08/83
Solar Radiation (mj) Epply Pyranometer	061	1.6		08/06/82-10/11/82 06/01/83-08/31/83	09/15/82-11/08/83
Net Radiation (mj) Net Pyradiometer	064	1.6		10/08/82-10/11/82	07/29/82-11/08/83
Wind Speed (m/sec) Met-One	076	10.0 *15.0	07/15/82-10/11/82	07/15/82-10/11/82 *	07/15/82-11/08/83
Wind Direction (Deg) Met-One	156	10.0 *15.0	07/15/82-10/11/82	07/15/82-10/11/82	07/15/82-11/08/83
Precipitation (mm) Tiping Bucket	123	0.6		08/06/82-10/11/82 06/10/83-08/31/83	07/15/82-11/09/82 04/13/83-11/08/83
Belfort		0.6		11/16/82-04/12/83	11/10/82-04/12/83

* The bush site wind instruments were mounted at 15.0 metres.

Methodology

The general objectives of the study were:

1. to describe the microclimate of a hybrid poplar farmed forest environment.

2. to compare the microclimate of a hybrid poplar farmed forest environment with that of an adjacent open site.

Archiving the data from the sites in a usable form was the first step after data measured in the field were uploaded from the cassette tapes. For the open and bush sites computer files of daily records were created with the following general format: station identification, observation height (decimetres), year, Julian date, frequency of observation code and element code number (similar to AES climatological archives) followed by 24 hour observations.

For the height even numbers were used for measurements taken above ground in decimetres. Odd numbers were used for soil temperature measurements. In the element code numbers the first digit signified for 0 or blank, the instantaneous values measured on the hour; for 1 total amounts through the previous hour for parameters such as solar radiation and precipitation or mean values through the hour for parameters such as temperature, humidity, or winds; for 2 maximum values; for 3 minimum values. A 4 with the wind direction was used to indicate the standard deviation through the hour. The remaining three digits of the element code defined the type of parameter being measured. Please refer to Table 1 for dates of parameter observations and for definitions of individual element codes. Correction factors for instrument error were applied where necessary. All values were recorded to one decimal place. Where an hourly value was missing -999.9M was substituted for that value. Units used for recording temperatures were degrees Celsius. For precipitation millimetres were used. Radiation was in megajoules/metre^2. Humidity was measured in percent. Wind speeds were in metres/second and wind directions were in degrees with 360 being North.

The above files could be used for general description of the climate for the whole period of the study; however, for comparison between sites and for descriptions under different weather conditions further breakdown and refinement were required. It was decided to categorize the data into three classes, nominally cloudy, partly cloudy, and clear based upon solar radiation measured at the open site. The amount of solar radiation received in addition to being influenced by the sky cover is also dependent upon the declination of the sun and the length of days. A table with the total possible solar radiation at 44 degrees North for each day was used as a reference in determining the classification. The ratio of the measured radiation to the total possible radiation was used as the selection criterion in placing individual days into the appropriate categories. In order to determine the boundaries of the classes a histogram was plotted for the daily radiation measurements. The distribution that resulted was trimodal. Based upon this histogram cloudy days were defined as those with a ratio of measured to total possible solar radiation of less than 0.34; partly cloudy days had ratios from 0.34 to 0.55; and days with ratios greater than 0.55 were classified as clear.

In order to carry out statistical analyses and comparisons between the open and bush sites, data sets were created by individual parameters with data from the two sites paired by hours. The classification of the days as cloudy, partly cloudy, or clear was also included in the analysis. Only days with complete observations from both sites were included in the analysis. Means and standard deviations were calculated for each hour for most of the parameters at both sites and graphed. Correlations were also calculated between the sites and data plotted by hours.

For wind directions a different approach had to be used to display the data. Wind roses for the open and bush sites were created showing frequencies of winds measured in hours from 16 directions under the three sky conditions.

A selection of graphs showing mean values and standard deviations of mean hourly readings at the open and bush sites under the three sky condition classes is presented in this paper for the following list of parameters:

1. Solar radiation
2. Air temperature at 1.2 metres
3. Air temperature at the surface
4. Soil temperature
5. Relative humidity at 1.2 metres
6. Wind speed

In addition changes from the previous hour are analysed for the above variables. Wind roses are presented for hours of wind from various directions. Although instantaneous maximum and minimum values were also plotted for these parameters they will not be presented here as their patterns closely follow those of the mean values and provide little additional information. Precipitation, because of its daily and hourly variability, also does not lend itself to this form of graphic display but it will be considered in tabular form in the following section on representativity.

Discussion:

Figure 3 illustrates the mean and standard deviation of the hourly values of solar radiation at both the bush and open sites and Figure 4 illustrates the mean and standard deviation of the hour to hour changes for this variable. The vertical bars along the mean trend lines show standard deviations in the measurements for individual hours. The differences show more variation than the means of actual values since over the season a smoothing effect in the measurements for hourly values results. Measurements taken at Codrington confirm statements made in aforementioned studies e.g. Johnson et al (1971). In general greater amounts of solar radiation are measured at the open site than at the bush site as less light is intercepted and reflected in the open before it reaches the sensor. Topography, foliage, and the alignment of the trees particularly influence the amount of solar radiation measured in the bush. Photograph 6 is a picture of the open site tower and instrumentation. Photographs 7 to 9 show the bush site instrumentation. Solar radiation sensors (resembling light bulbs) were mounted on the south sides of the towers so as to minimize shading effects by the towers or other instruments. Guy wires can have some minor effects. In the bush, however, they were located so as to minimize the effect on the recorded radiation. Often peaks occurred at approximately 11 a.m. and 3 p.m. which can be attributed to more open exposure to the sun by the sensor at those hours. The alignment of the trees (i.e. plantation structure) provided natural openings through which the sun was able to reach the sensor more directly than at other times of the day. Typical times for the development of cumulus clouds may also be partly responsible; however, this is a relatively minor cause. The difference in radiation measured between the open and bush sites increased with the clarity of the sky. Measurements increased at both sites; however, the increase was greater at the open site when the

Photo 8. Roger Street is shown servicing a CR-21 datalogger at the bush site. To the right near the Epply pyranometer a camera has been set up to photograph the forest canopy above the instrumentation.

Photo 9. A view of the forest canopy through a fisheye lens near the Epply pyranometer at the bush site. The pyranometer was mounted on the south side of the tower so as to minimize any shading effects from the tower or other instrumentation.

sky was clear. J.M. Powell stated "A clearcut reflects a greater proportion of solar radiation than a forest which absorbs 60 to 90 percent of the solar energy received" (Johnson et al, 1971). The clearcut may not actually reflect more solar radiation; however, the forest does absorb 60 to 90 percent of the total solar energy received. Much of this is long wave terrestrial radiation which is re-radiated back toward the ground by the trees within the forest. In the open most of this terrestrial radiation would escape particularly on clear nights. Under cloudy skies there was less difference between the sites. Clouds have a similar effect to the forest canopy. Less solar radiation is received at both sites and less terrestrial radiation is lost. Radiation appeared to increase earlier by about an hour at the open site. The hill to the south of the bush site would provide some shading to the bush radiation sensor particularly in the early morning and late evening, outside the summer months. In Figure 4 the standard deviations would be larger when the days were classified as partly cloudy because they could be "partly cloudy" for different reasons. For example it may have been sunny in the morning but cloudy with showers in the afternoon. Another day may have been "partly cloudy" all day.

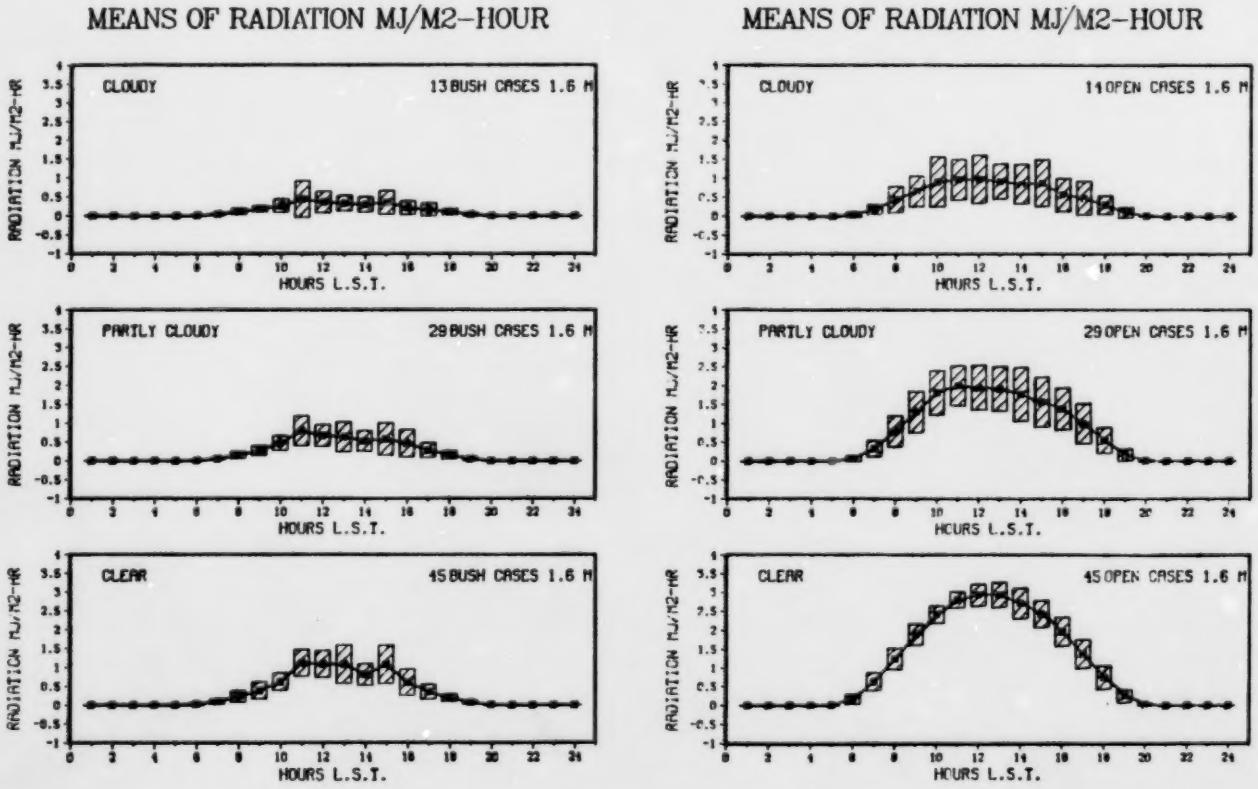


Figure 3.

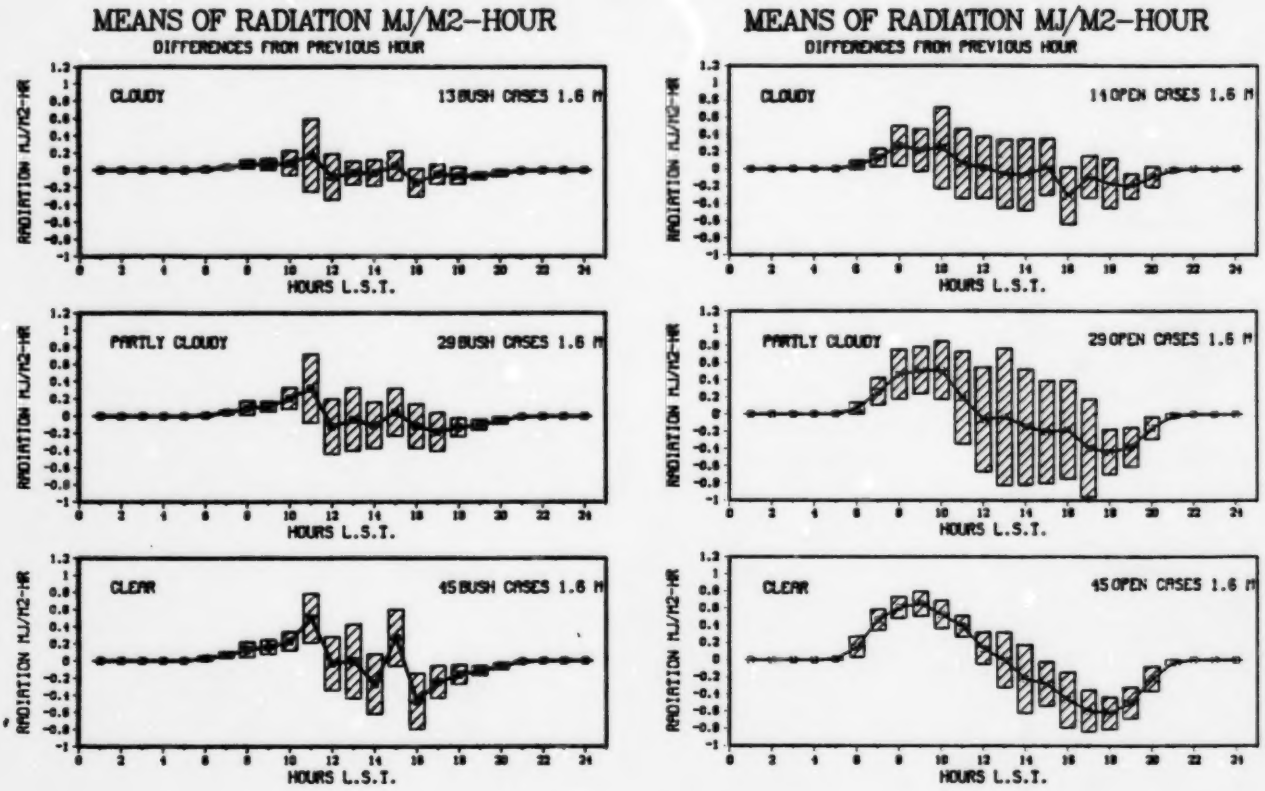


Figure 4.

Figure 5 shows the means and standard deviation of temperatures measured at 1.2 metres and Figure 6 the mean and standard deviation of the changes from hour to hour in mean temperatures. Temperature changes can result from advection of air from another area which has different temperature characteristics as in the case of a frontal passage or when there is a local wind such as a lake breeze. They can also result from a change in the amount of heat energy as a result of changes in radiation. As can be seen patterns for temperatures are quite similar between the open and bush sites. On cloudy days there were little differences in values between the sites. Also on these days daily maximum and minimum temperatures were close. Maximum temperatures were slightly higher and minimum temperatures slightly lower at the open site when compared to the bush site. The daily temperature range increased with the clarity of the sky and also the difference in temperature between the sites. The mean temperature patterns responded most often to increases and decreases in radiation and thus there is a similarity in the radiation and temperature curves. Temperature changes were usually slower in the bush. In addition to differences in radiation patterns wind speeds and directions would also influence temperatures. Thus there would be differences in temperature changes due to advection. The lag in temperature rise in the bush is most evident in the morning after sunrise particularly on clear

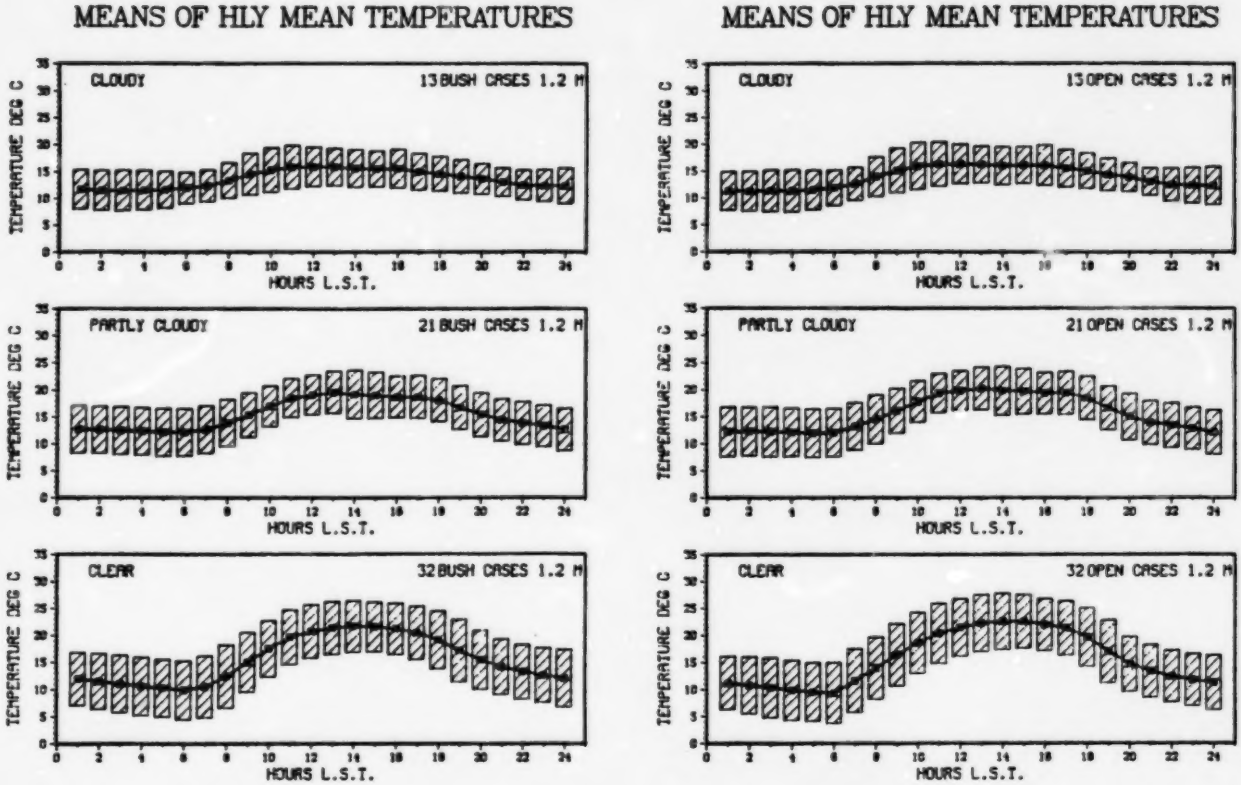


Figure 5.

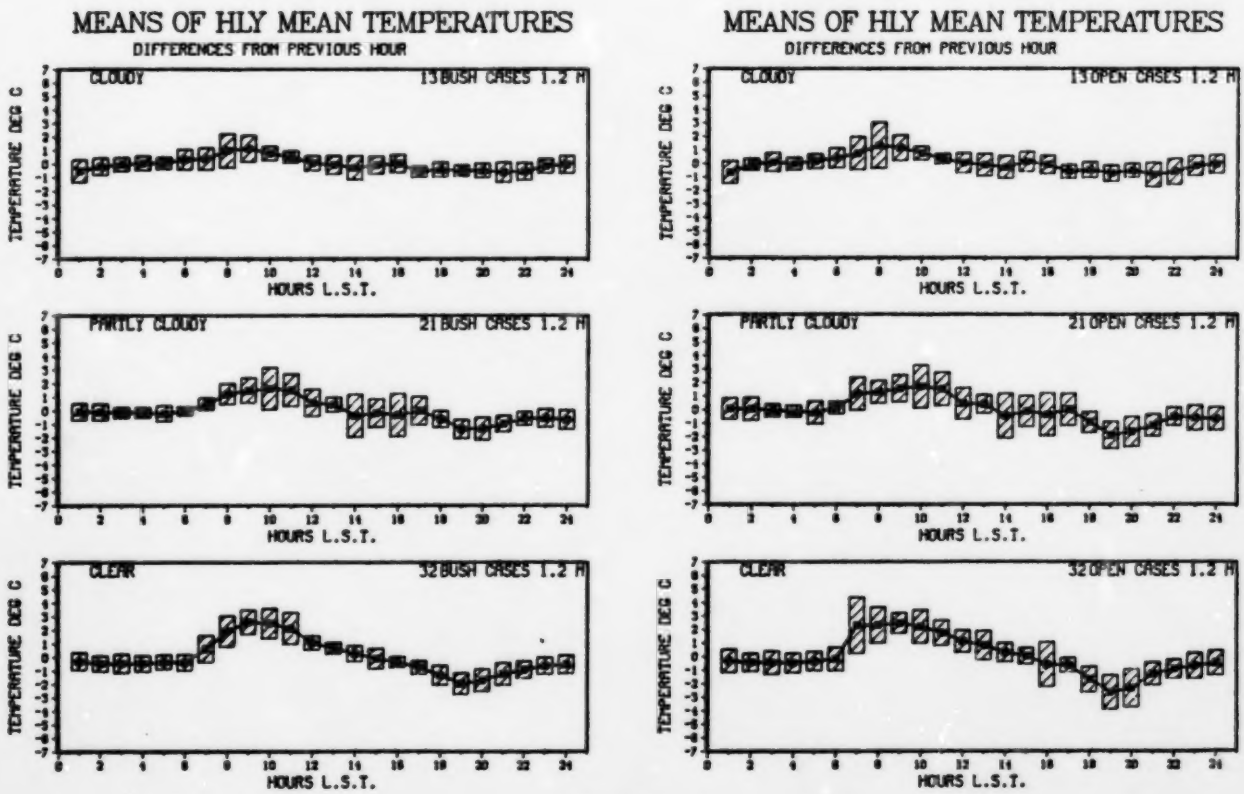


Figure 6.

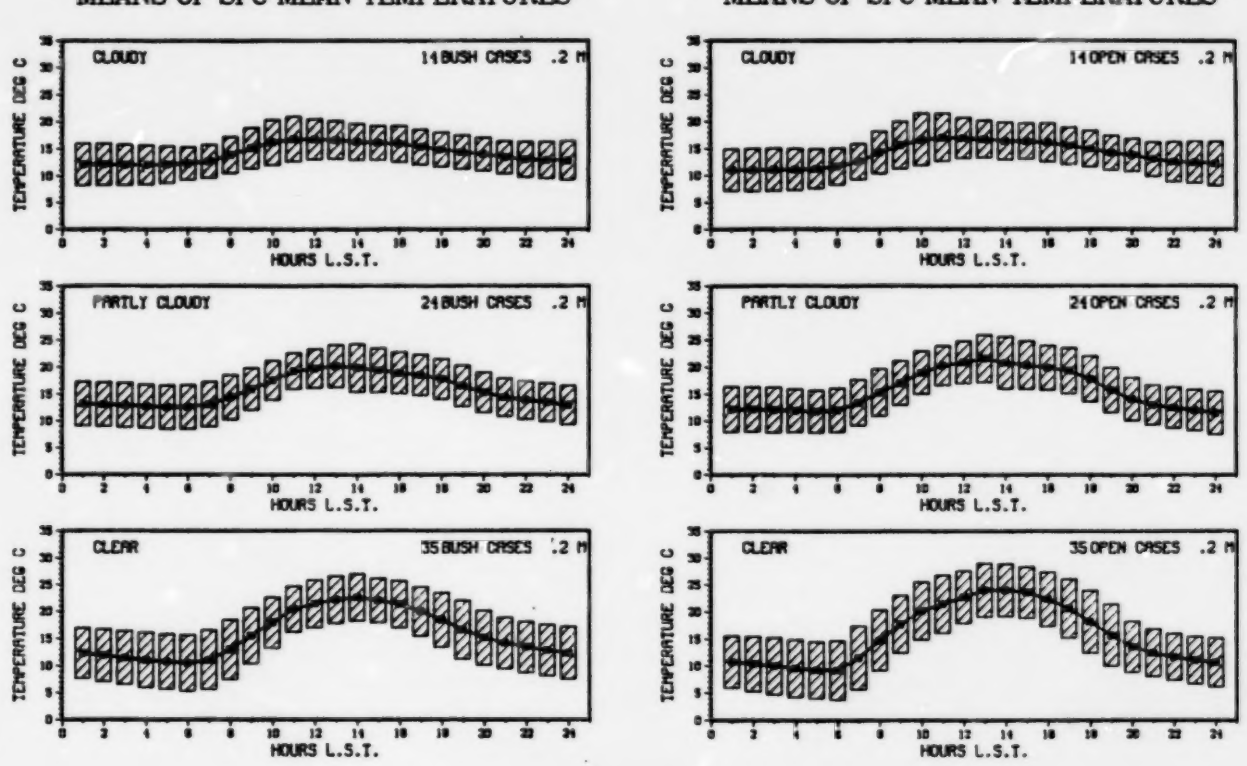


Figure 7.

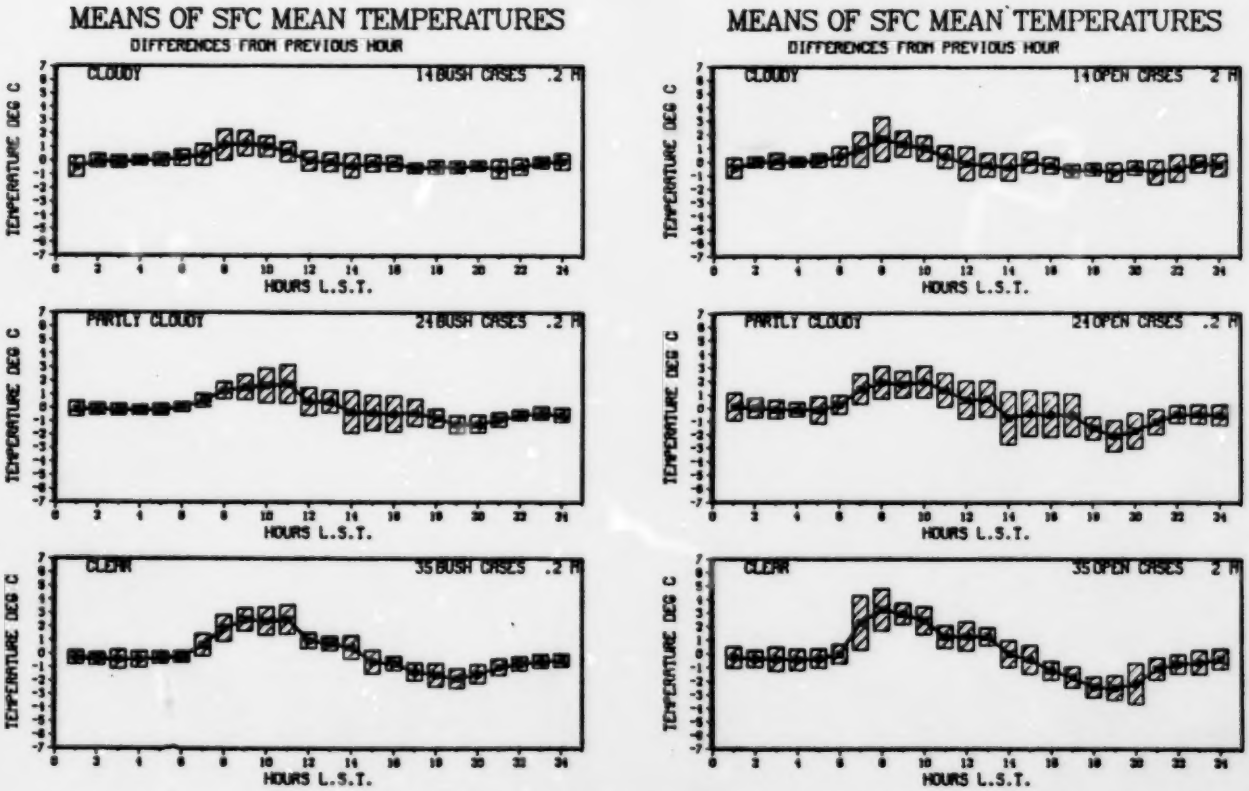


Figure 8.

days. In the open there is a rapid rise whereas in the bush the same temperature increase requires about three hours. Irregularities in standard deviations on the graphs would result from differing times of such phenomena as frontal passages, precipitation, etc..

Figure 7 depicts mean and standard deviation of the hourly mean temperatures next to the ground and Figure 8 shows the mean and standard deviation of the hour to hour differences in these temperatures. The patterns of the temperatures measured near the ground at the bush and open sites are similar to those measured at 1.2 metres. The curves are slightly more pronounced for near the ground than for higher in the air particularly when the skies are clear. On clear days at 1.2 metres in the open at 6 a.m. the temperatures averaged 9.3C and 10.5°C in the bush. At 1 p.m. on clear days at 1.2 metres the temperatures averaged 20.3°C in the open and 19.6°C in the bush compared to near surface where the temperatures averaged 24.0°C in the open and 21.7°C in the bush. These differences in temperature with height can be explained by differences in circulation and by the proximity to the ground. At a slightly higher height there would be more mixing of the air by wind, convection etc. Near the ground vegetation and physical barriers would cause more frictional drag or otherwise impede air motion. The ground also has a higher specific heat than the air. Near the surface it would warm up faster in the sun or cool more rapidly in the sun's absence. In the bush radiation from the foliage of the canopy would also provide some warmth at the 1.2 metre level. Thus there would be less difference in temperatures within the bush than in the open. Hour to hour changes near the surface at the bush and open sites were similar to those at 1.2 metres except that they were slightly greater in extent.

Hourly means and standard deviations of the mean soil temperatures and their hour to hour differences are depicted in Figures 9 and 10 respectively. Soil temperatures and radiation were measured for a longer period of time than air temperatures and other parameters at the bush site. Thus soil mean temperatures should not be directly compared to the air mean temperatures; still, there was much less diurnal temperature variation in the soil as compared to the air. Because of the mass of the soil, specific heat, and lack of mixing soil temperatures change much more slowly than air temperatures. There is also a lag in the time of temperature changes in the soil compared to those of the air. The soil temperatures continue dropping until about 11 a.m. before they slowly begin to rise at the 10 cm depth where the probes were located. Maximum temperatures occurred around sunset when air temperatures were already falling. The influence of the amount of solar radiation received at the sites was still evident. On clear days for example the daily temperature range was about 4.5°C in the open and only 2.5°C in the bush. There was more diurnal variation on clear days than on cloudy days and there was more variation in the open than in the bush. Seasonal variation in soil temperatures is much less than in air temperatures. Standard deviations in soil temperature changes are small because of slow response to temperature changes in the air above by the soil.

Figure 11 shows the means of hourly mean relative humidity and Figure 12 illustrates the means and standard deviation of the hour to hour differences for this parameter. On days classified as cloudy the open site night-

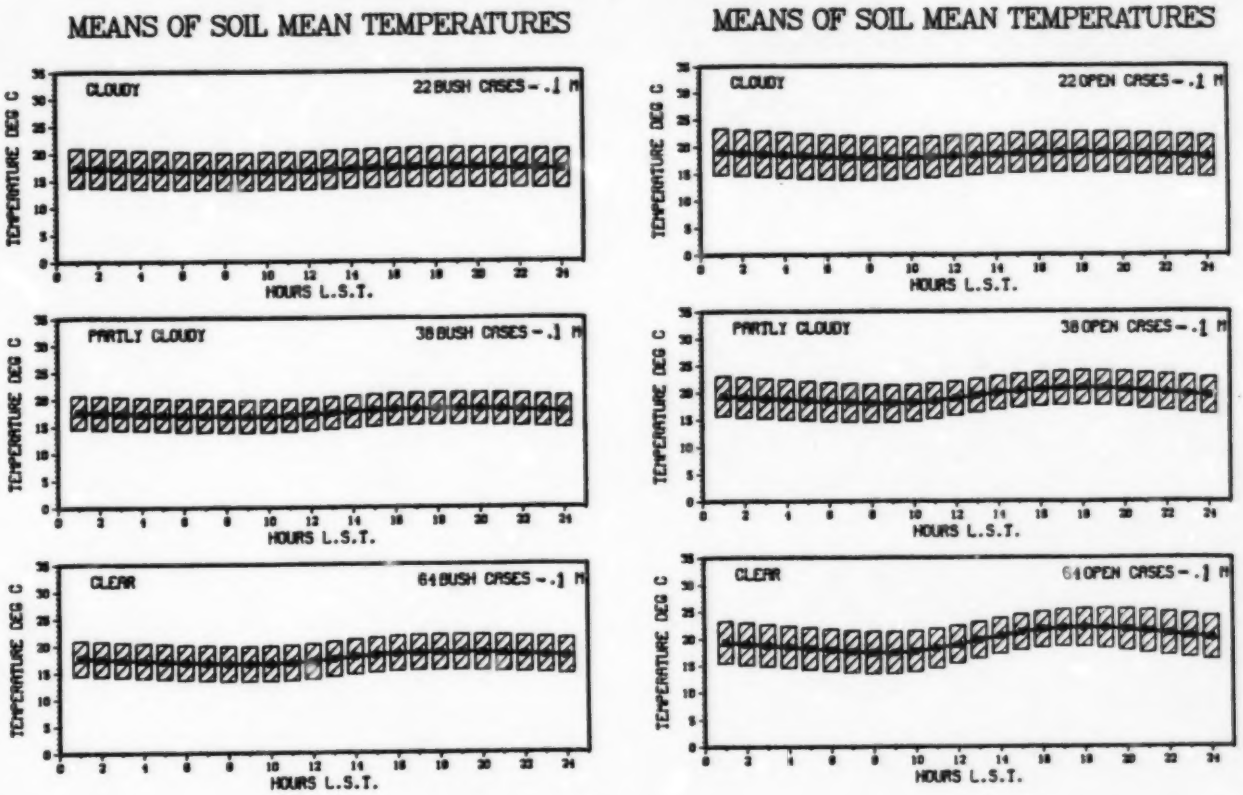


Figure 9.

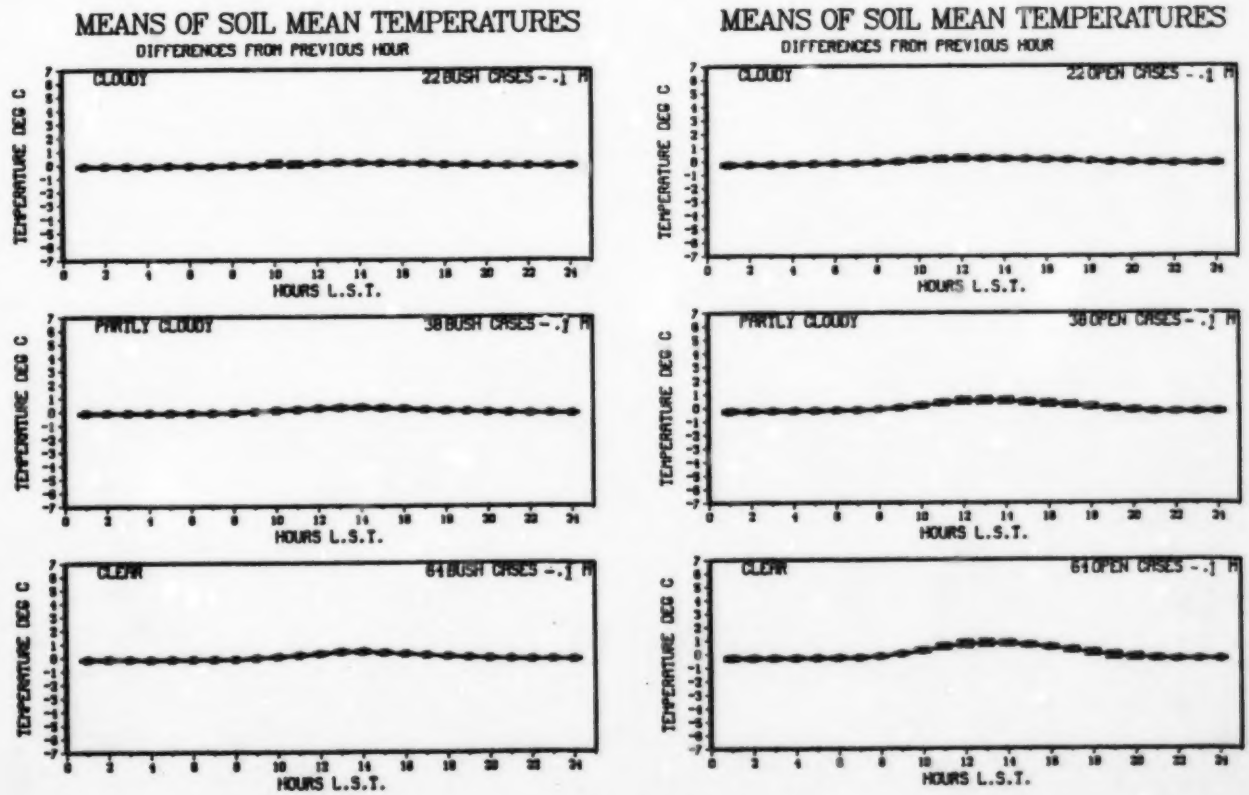
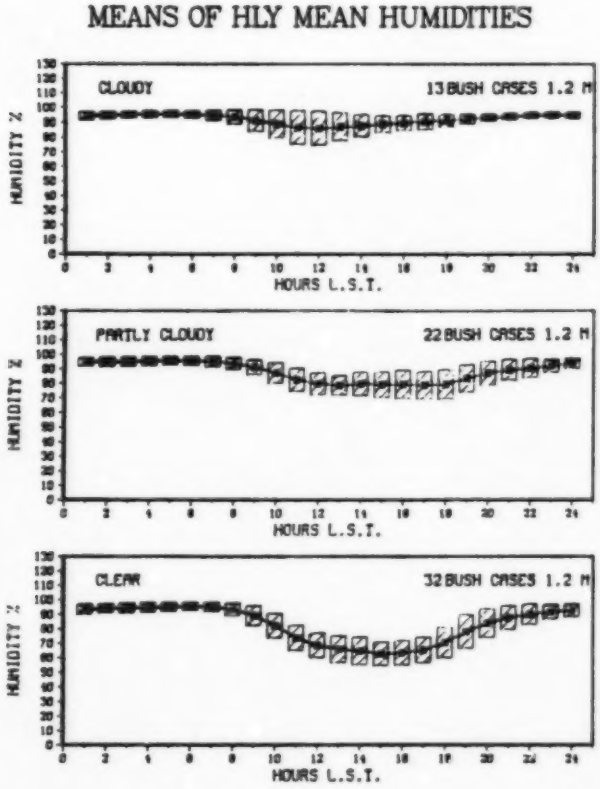


Figure 10.



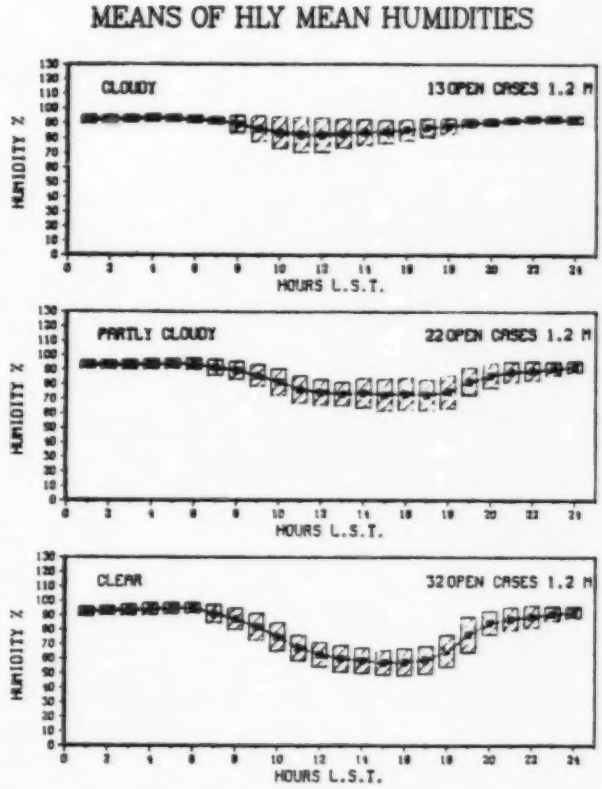
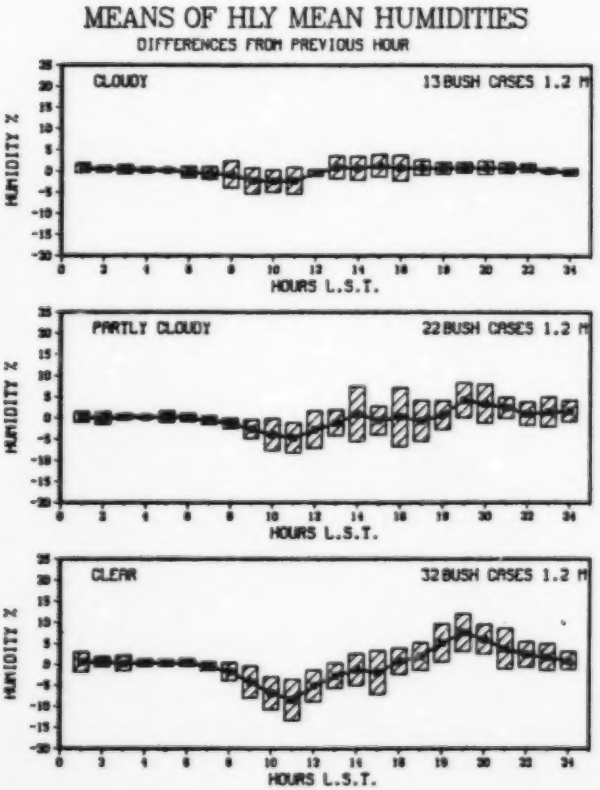


Figure 11.



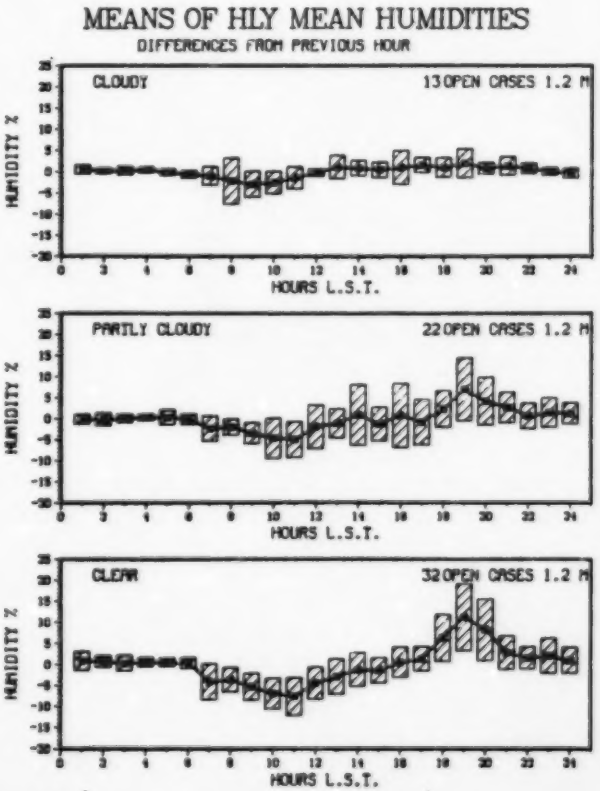


Figure 12.

time relative humidities were close to but slightly less than bush site relative humidities. These were usually above 90%. As the day progressed open site humidities decreased more rapidly than those in the bush. Around mid-day, bush humidities averaged about 5% higher than open site humidities. At both sites, from mid-day, average values of relative humidity again gradually increased until midnight when they again approached 90%. Standard deviations are often lower under cloudy conditions. Similar patterns existed for partly cloudy and clear skies; however, during the day humidities dropped lower than with cloudy skies. For example on clear days humidities dropped to 53% in the open and 60% in the bush. The increase in humidity under partly cloudy and clear skies did not usually occur until around sunset. There was also a greater drop in the open site than in the bush site during the day. Absolute humidities probably were not very different between the sites. Transpiration by the trees would provide some extra moisture in the bush, but higher temperatures at the open site were more responsible for its lower relative humidities. These data confirm Powell's statement in Johnson et al (1971) that atmospheric humidity is slightly higher in the forest. Patterns of relative humidity differences between hours are quite similar between the open and bush sites. In the bush there is more of a smoothing effect however. This can be due to a decrease in air circulation compared to the open site. Also there was less direct sunlight which could cause more rapid temperature changes in the bush. Figure 12 reveals that standard deviations are greater in the open. This is particularly noticeable on partly cloudy days when there can be variable cloud cover from hour to hour. Higher standard deviations around 7 p.m. are probably due to change of sunset times when humidities tend to increase more rapidly. This is also more evident at the open site where more solar radiation is received.

Wind is a vector quantity with both speed and direction components. Thus wind speeds and hour to hour differences in speed will be considered in Figure 13 and Figure 14 respectively. Figures 15 through 17 show the total hours of winds measured at the bush and open sites under cloudy, partly cloudy, and clear skies respectively.

Under all sky conditions mean wind speeds measured at the bush site just above the canopy were reduced. The bush site tower was 15 metres high compared to the open site tower which was 10 metres high. Wind speeds do decrease as the ground is approached as is discussed by Geiger (1966), however, the change of wind speed with height is logarithmic. Wind speeds increase quite rapidly between the surface and two metres, however above six metres the rate of increase with height is only a small fraction of a metre per second. The difference in the wind speeds at the open and bush sites cannot then be significantly attributed to the difference in tower height. Except when there were storms or frontal passages etc., hourly wind speeds increased during the day and lowered at night. On cloudy days average peak wind speeds occurred earlier (usually late morning). On clear days winds increased until about 4 p.m. after which they declined. Standard deviations revealed more variability on cloudy and partly cloudy days and the mean curves were less smooth than on clear days. Atmospheric disturbances such as fronts which are responsible for cloud and precipitation would be more prevalent on cloudy and partly cloudy days. These would also cause more wind.

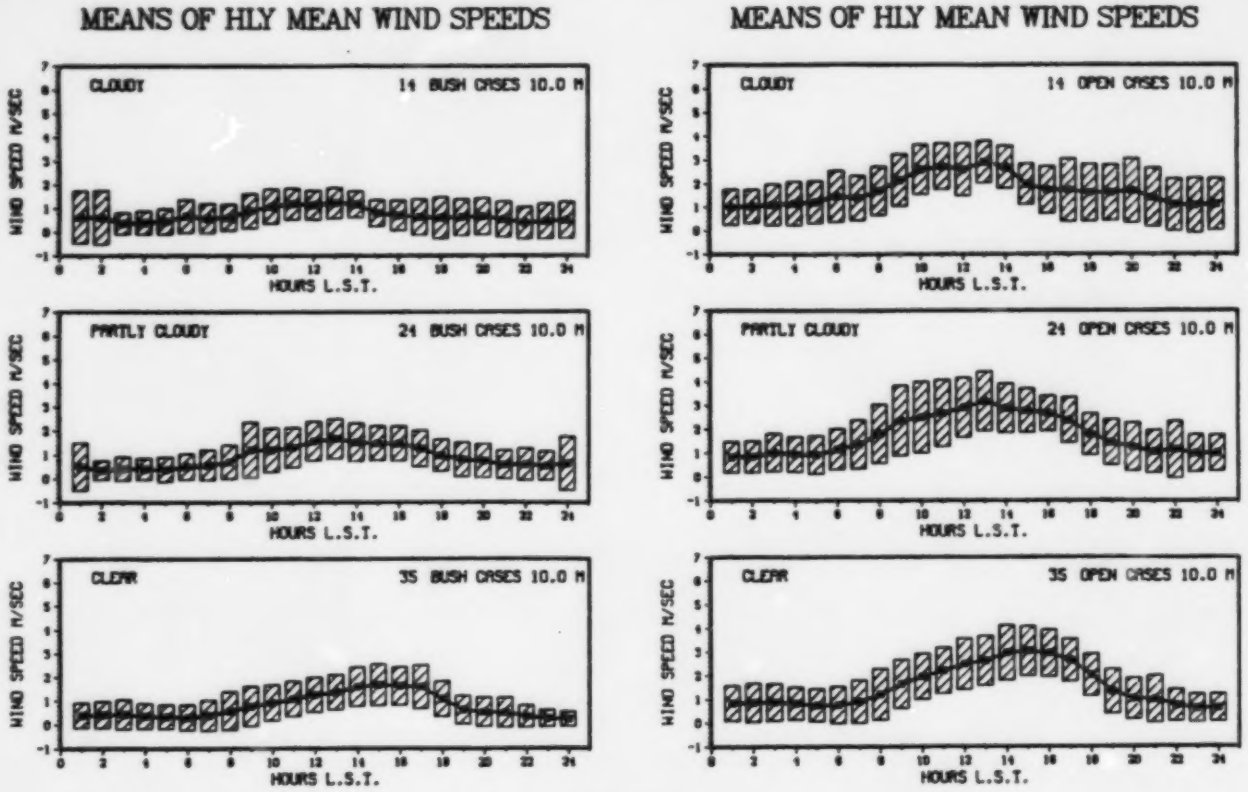


Figure 13.

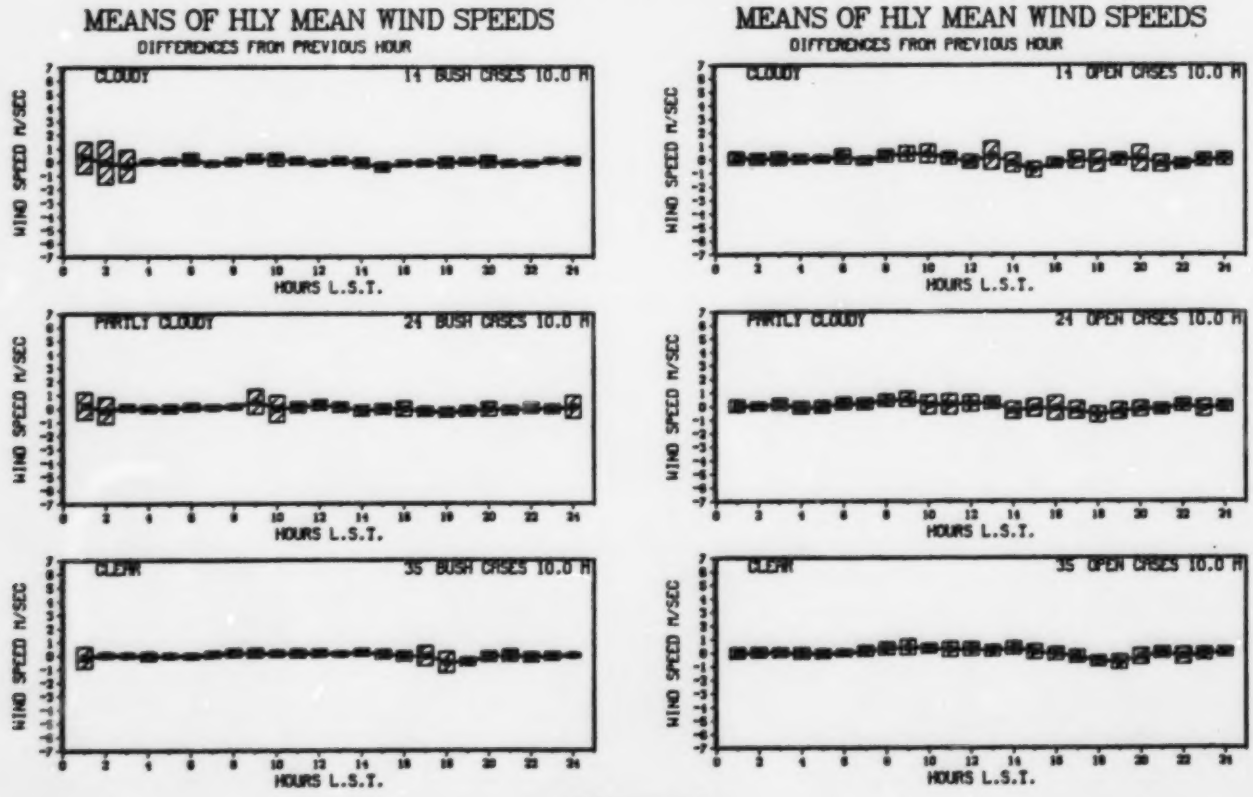


Figure 14.

Figure 14 reveals that there is more variability in the means and standard deviations of hour to hour differences in wind speed. (Note there is a difference in the vertical scale of figure 14.) When weather systems and fronts pass through they can have as much or more effect on the wind speed as the effects of temperature and radiation which are reflected by the hour of day. Thus there is more variability than with the latter mentioned parameters.

In the wind roses shown in Figures 15 to 17 each circle represents 20 hours of wind. It can be seen that on cloudy days winds from the northeast were much more common than on partly cloudy or clear days. Counter clockwise air circulation around low pressure systems would be one explanation for this particularly when the low passed just south of the station. This characteristic was more noticeable at the bush site. Under all sky conditions there were less hours of wind from the south and southwest at the bush site than at the open site. Prevailing winds were more west-southwest at the bush site rather than south-southwest as at the open site. The location of the hill and the alignment of the trees in straight rows from west-southwest to east northeast within the plantation could be partly responsible for this. Under partly cloudy skies prevailing winds had a more westerly component than with cloudy skies. West and west-southwest winds were more common in the bush while there was more of a southwest or south-southwest frequency at the open site. As stated with the cloudy skies, topography may have had a significant influence. Prevailing winds would be the normal westerly zonal winds. On the wind roses more winds appear from all directions toward both sites when it was clear because there were more clear days. In fact the total for clear days almost equals the sum of cloudy and partly cloudy days.

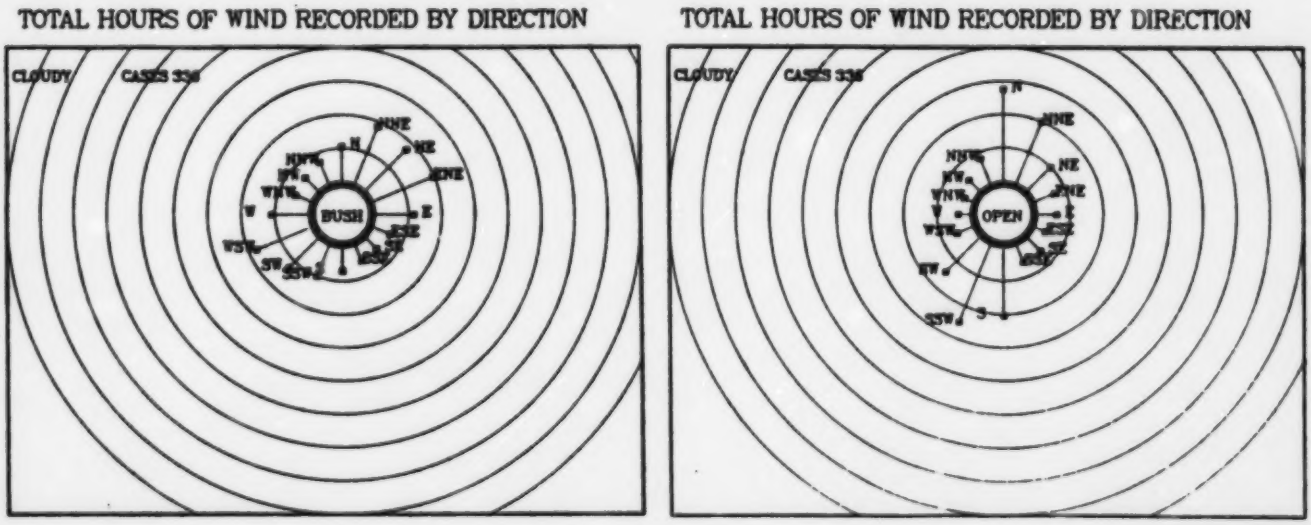


Figure 15. Frequencies of wind directions recorded on cloudy days at the bush and open sites. Each circle represents twenty hours of wind measured.

On clear days south-south west continued to be the prevailing direction for the open site while in the bush the prevailing direction was more west-southwest. This west-southwest wind direction was almost parallel to the alignment of the trees in the plantation. While the open site was much more open than the bush site there were some well developed trees to the east and west of the field which may have had some steering effect on the open site winds thus giving them more northerly or southerly components than would be expected from the zonal winds.

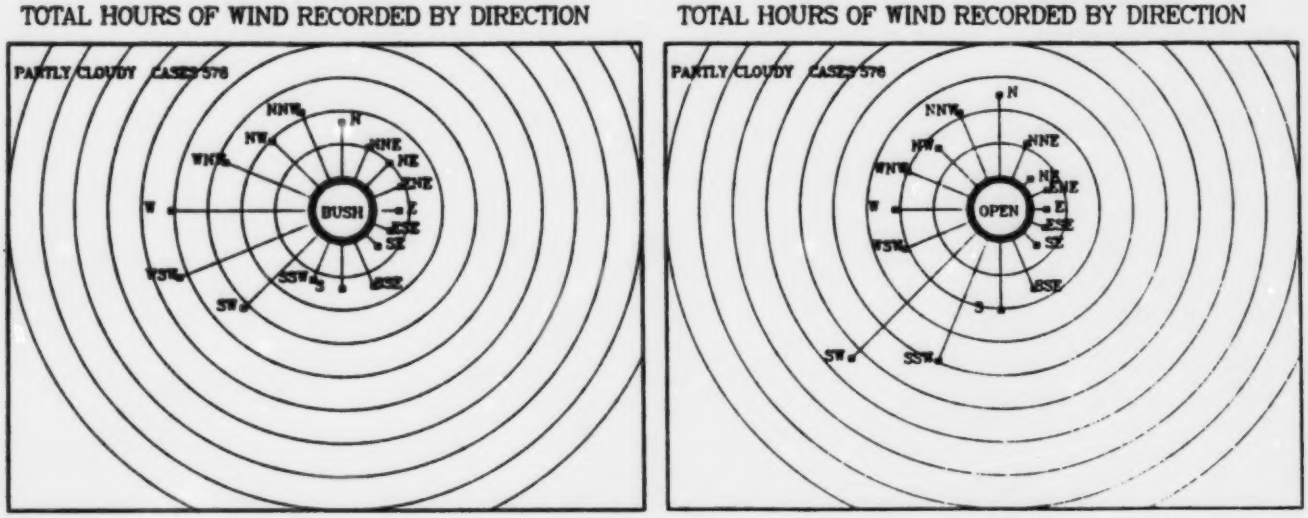

TOTAL HOURS OF WIND RECORDED BY DIRECTION
PARTLY CLOUDY CASES 576
BUSH
TOTAL HOURS OF WIND RECORDED BY DIRECTION
PARTLY CLOUDY CASES 576
OPEN

Figure 16. Frequencies of wind directions recorded on partly cloudy days at the bush and open sites. Each circle represents twenty hours of wind measured.

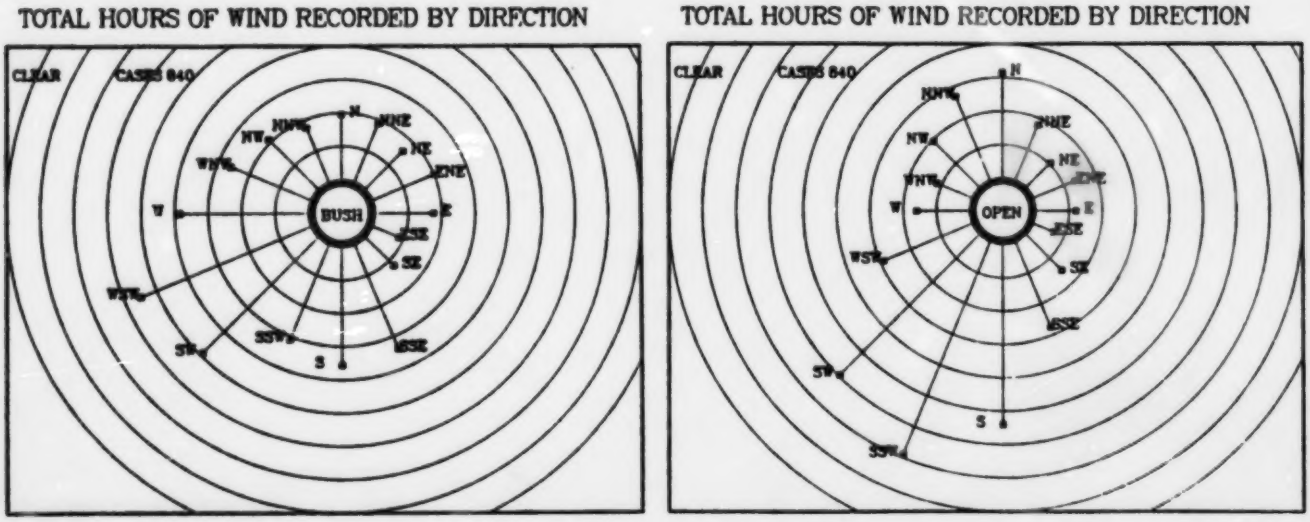


Figure 17. Frequencies of wind directions recorded on clear days at the bush and open sites. Each circle represents twenty hours of wind measured.

Typical Days

The methodology and graphs thus far described can be used for climatological statistics; however, they do not portray individual days or relate them to synoptic weather patterns. A day may be classified for example as partly cloudy on the basis of the amount of solar radiation measured but it may have been sunny in the morning and cloudy with showers in the afternoon. In order to better illustrate the characteristics of cloudy, partly cloudy, and clear days at the open and bush sites eight typical days (2 cloudy, 3 partly cloudy, and 3 clear) were selected from the 1982 data set. They are listed below along with their dates, radiation ratios of solar radiation measured on the day to the total possible solar radiation for that day, bright sunshine hours measured at Peterborough, Ontario and a brief description of the synoptic weather pattern and associated weather.

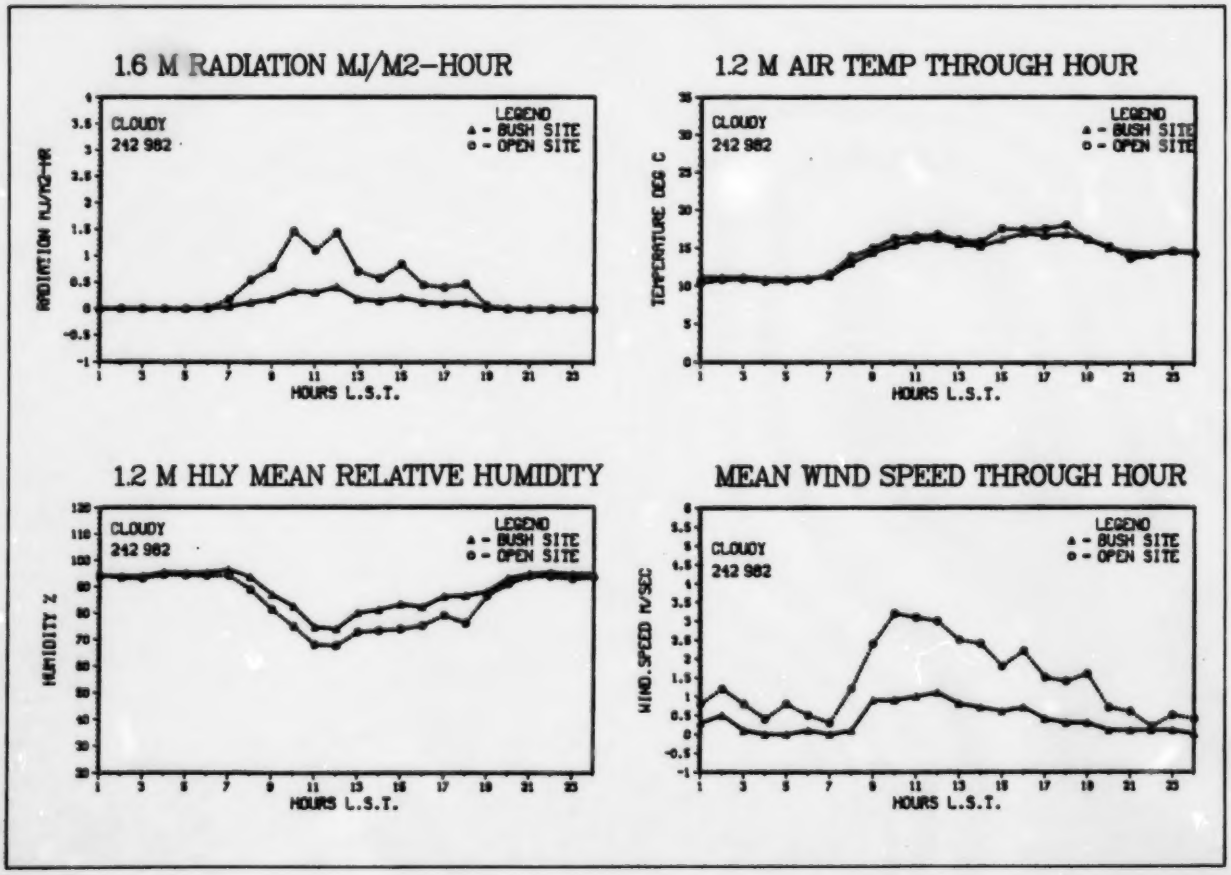
Table 2 Typical days

Day	Date	Ratio	Sun Hours	Synoptic Weather
Cloudy Days				
242	Aug. 30	0.3	1.1	Cloudy, with no precipitation, high pressure system east, lows to west over Moosonee and Windsor, cold front over Lake Huron.
267	Sep. 24	0.1	0.4	Clouding over, with afternoon rain. Ridge over eastern Ontario, Low over Michigan with a cold front north of Codrington.
Partly Cloudy Days				
225	Aug. 13	0.5	6.0	In a col between a high over Hamilton and Nova Scotia low.
240	Aug. 28	0.5	10.1	Clear a.m., rain p.m., frontal passage on the trailing edge of a low and the leading edge of a high.
255	Sep. 12	0.5	5.4	Sunny, hazy, in the warm sector of a wave running into northern Quebec.
Clear Days				
223	Aug. 11	0.6	10.6	On the leading edge of large Wisconsin high behind a low over Labrador.
232	Aug. 20	0.6	12.1	Between a front to the north and a cold front from south of Lake Ontario to a low on the Quebec-Labrador border.
251	Sep. 8	0.7	11.5	A high over southern Ontario and Manitoba, with a ridge to the Maritimes, 990 mb Hudson Bay low.

A selection of graphs showing meteorological parameters as measured at the open and bush sites on the days follows and will be discussed in greater detail later in this paper.

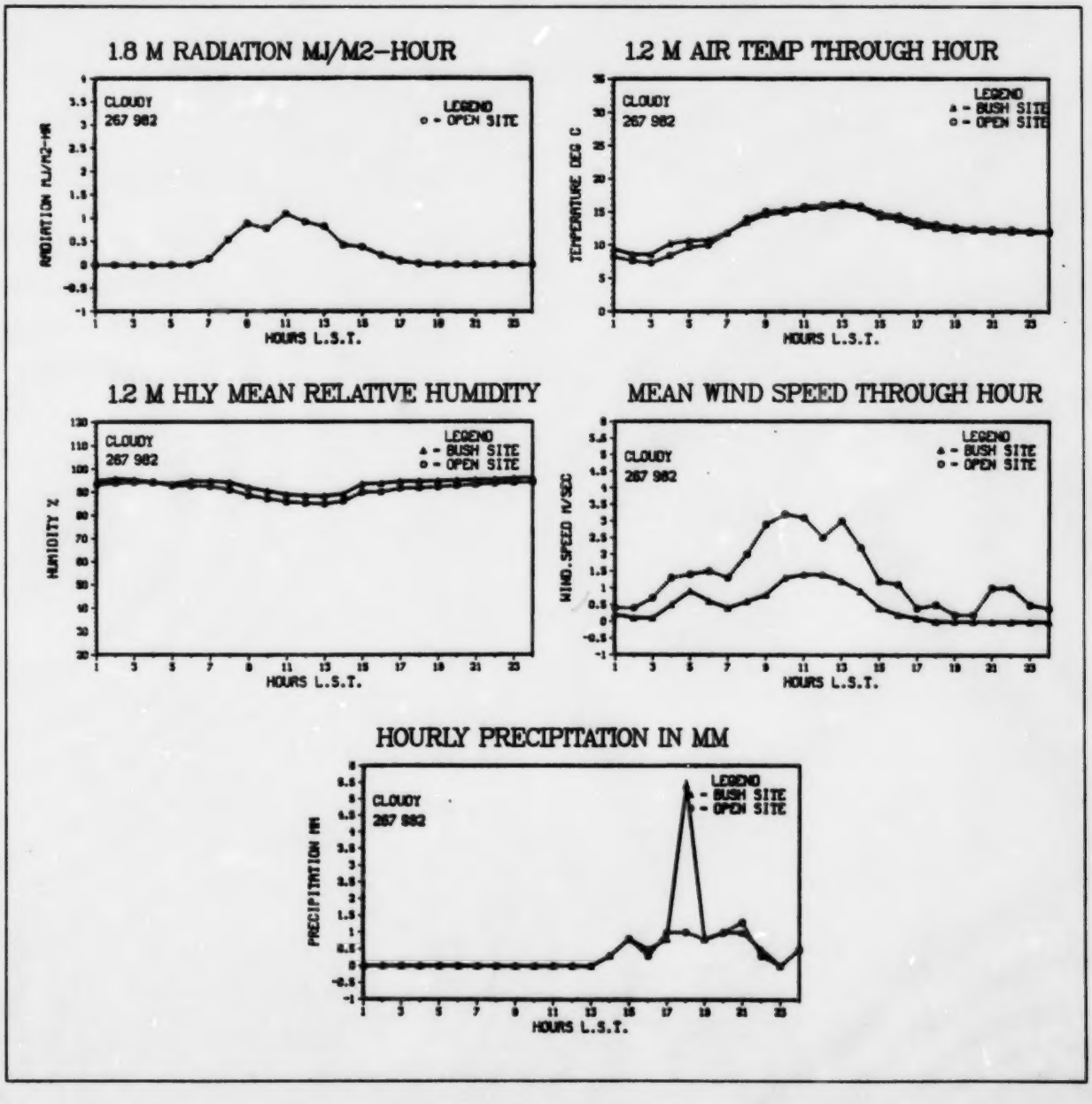
Cloudy Days

Day 242, August 30, 1982 is an example of a cloudy day with no precipitation. Radiation was reduced at both the open and bush sites, although some solar radiation reaching 1.6 megajoules was received in the morning hours at 1000 EST and noon. Cloud thickened in the afternoon ahead of cold and warm fronts advancing from the northwest and southwest respectively. Under cloud, temperatures recorded at both sites were close throughout the day, although the open site temperatures were slightly higher during the day. In the bush the maximum and minimum temperatures for the day were 17.8°C and 10.7°C whereas at the open site they were 19.8°C and 9.8°C respectively. There were similar patterns for relative humidity curves for both sites. The humidity dropped from about 95% at 0700 at both sites to near 75% in the bush and 68% in the open at noon. Through the afternoon the humidity rose again until about 2100 when it was again in the mid nineties at both sites. Wind speeds rose to about 3.5 metres per second in the open by 1000, then slowly declined. In the bush speeds only reached about 1.2 metres per second by noon. In



fact speeds were low in the bush all day. In the morning the prevailing wind direction was south-southwest and later in the day it became light and variable. Wind speeds at the bush site would be lowered in the morning by the topographic influences of the hill to the south and the trees.

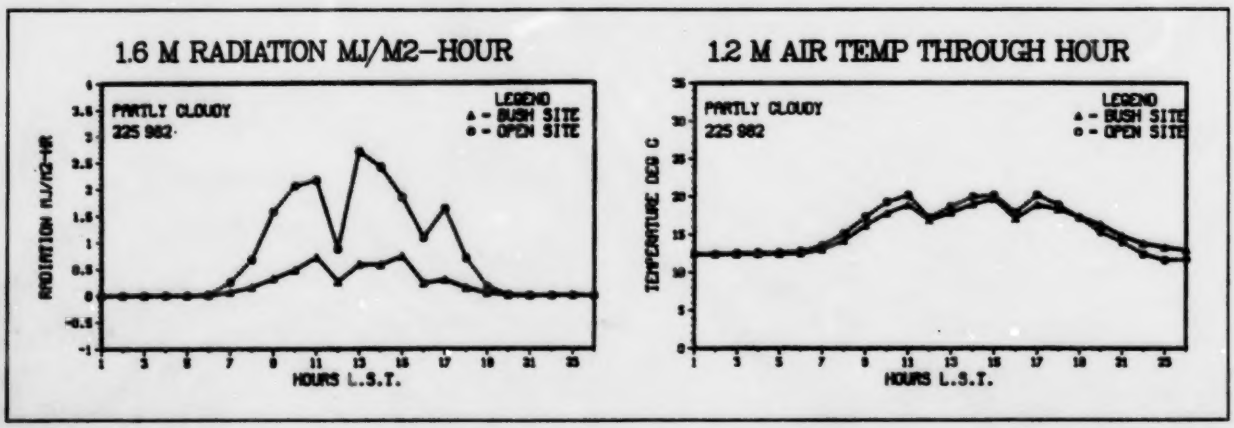
Day 267, September 24, 1982 is an example of a cloudy day when there was a considerable amount of rain. A total of 23.2 mm was measured in the bush while 14.6 mm was measured in the open. A low pressure cell moved in from the west which by late afternoon was directly over Codrington. Showery precipitation along a cold front was recorded around 1800. This would be

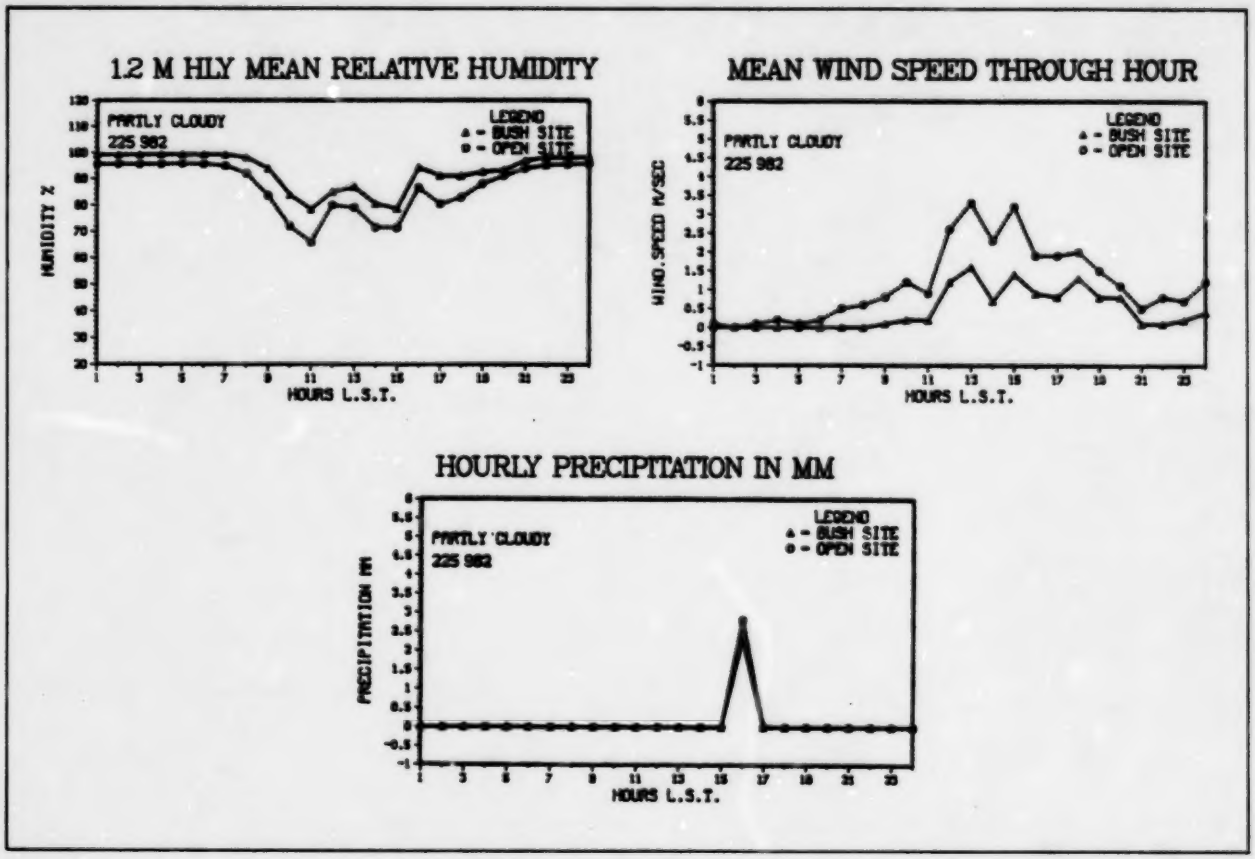


responsible for the peak at 1800 in the bush. It is possible that the local nature of the precipitation may have been responsible for the greater amount of rain recorded at the bush site. Bush site radiation measurements were missing; however, at the open site it only reached 1.2 megajoules by 1100, then started to fall. Humidities at both sites remained at or above 90% throughout the day. Temperature had a small range and it was almost identical at both sites. The bush site maximum and minimum temperatures were 16.3°C and 8.1°C while those for the open site were 16.7C° and 6.6°C respectively.

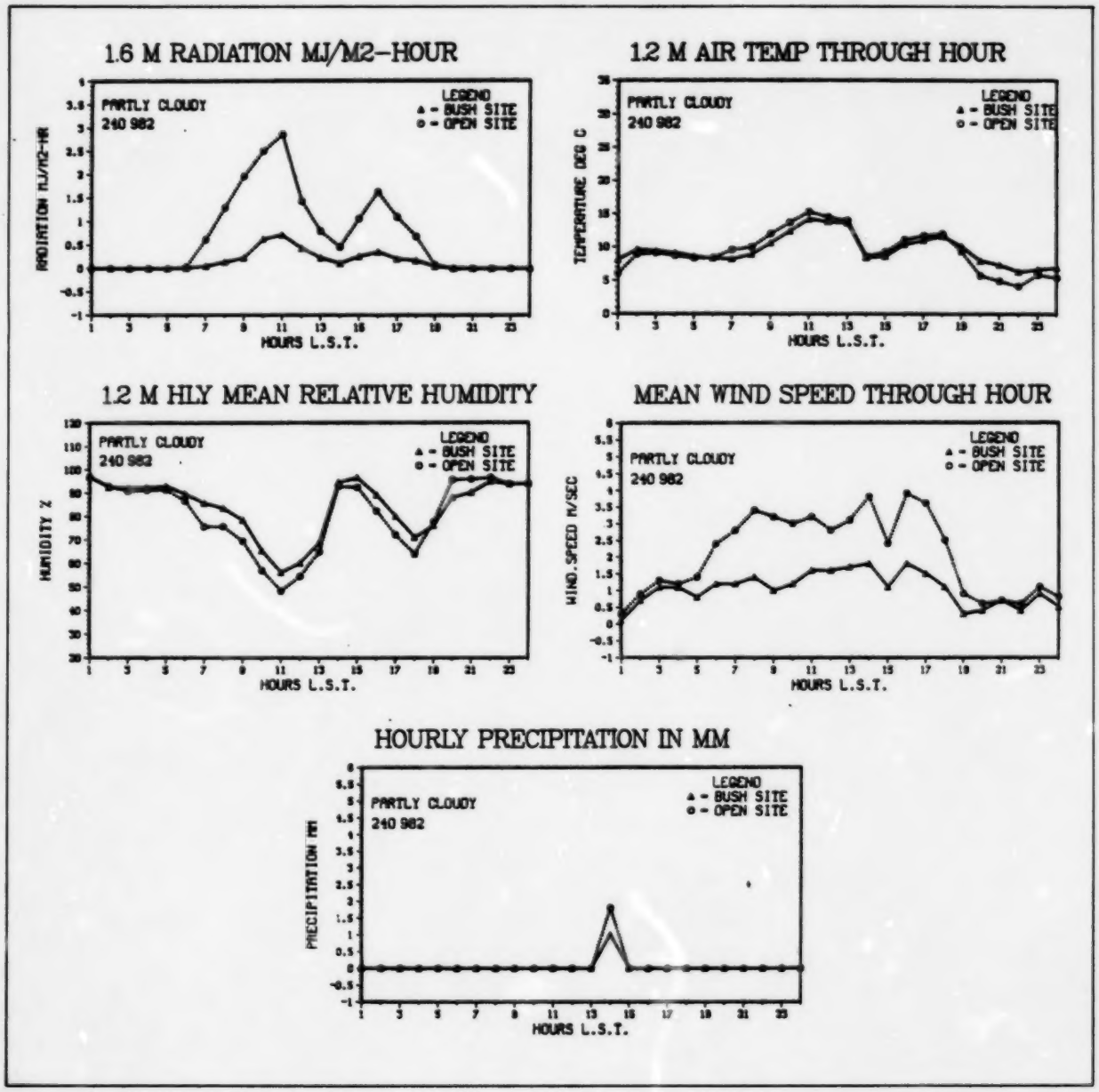
Partly Cloudy Days

Day 225, August 13, 1982 was a partly cloudy day with a variable amount of cloud. Codrington was under the influence of a col between two highs and a low pressure system to the southeast. A total of 4.6 mm of rain was measured at the bush site and 5.6 mm at the open site. This would be from a convective shower between 1500 and 1600 p.m. Clouds were cumuloform in nature as indicated on the 18Z map (1800 G.M.T. surface analysis map) which showed broken cloud with thunder showers in the past hour at Kingston, Ontario. Solar radiation, particularly at the open site dropped when these clouds would likely have been overhead; for example, at noon and 1600. The solar radiation recorder reached a maximum of 3 megajoules at 1300. Solar radiation was considerably reduced in the bush compared to the open site. Reduction of incoming solar radiation by cloud occurred at about the hours when the solar radiation sensor in the bush normally received its greatest amount of unobstructed sunlight. Relative humidities were high at night but dropped to about 80% in the bush and 65% in the open at 1100. The relative humidity rose again near noon then fell at about 1400. Then it rose with the afternoon shower. A glance at the graphs of radiation, temperature, and relative humidity reveals the interdependence of these three parameters. When the radiation drops, so does the temperature. Relative humidity is inversely related to the other two. Wind speeds are also positively related to solar radiation. In the bush there was a damping effect on all the variables. Wind speeds reached about 3.5 metres per second in the open but only around 1 metre per second in the bush. Wind directions were mostly southwest although they varied in showers. The high temperatures in the bush and open were 21.0°C and 23.1°C respectively and the lows 12.3°C for the bush site and 10.8°C for the open site.



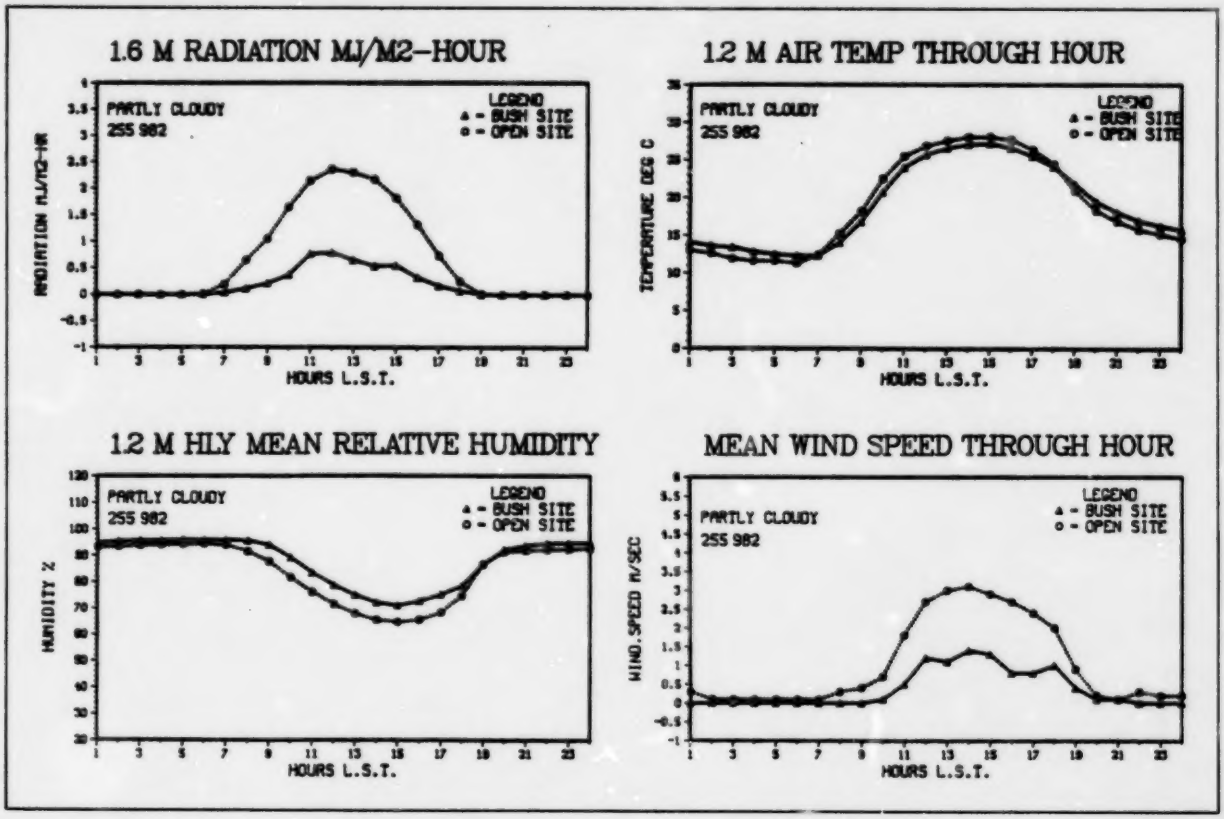


Day 240, August 28, 1982 was a day with a cold frontal passage. Part of the day was clear. In the early afternoon cloud and showers reduced the radiation. A total of 2.0 mm of rain was measured at the bush site and 3.6 mm at the open site. After the showers the sky again cleared by about 1600. As with day 225 the positive relationship between radiation, air temperature, and wind speeds remained as did the inverse relationship of these variables to relative humidity. At about noon there was a radical change in patterns. By 1100 the solar radiation climbed to about 3 megajoules in the open and 1 megajoule in the bush, then by 1400 it dropped to about .5 megajoules in the open and almost 0.0 in the bush. Later at about 1600 it again rose to 1.8 in the open and 0.4 in the bush then subsequently dropped toward sunset. The maximum temperature only reached 15.8°C in the bush and 17.3°C in the open. The drop in the radiation and the showers occurred at the time of day which is normally warmest. Under clear skies at night air temperatures dropped lower at the open site than at the bush site both in the early morning and in the late evening. The bush site minimum was 5.3 while the open site minimum was 3.4°C.



Day 255, September 12, 1982 was a warm hazy day. Codrington was in the warm sector of a wave behind a high off the Atlantic coast and warm air was brought in from over the United States. There was not much cloud as shown on the 12Z and 18Z maps; however, haze as reported by climate stations such as Campbellford, reduced the intensity of solar radiation received. On the basis of solar radiation measured at the open site, the day was classified as partly cloudy. Compared to other days described thus far the curves are

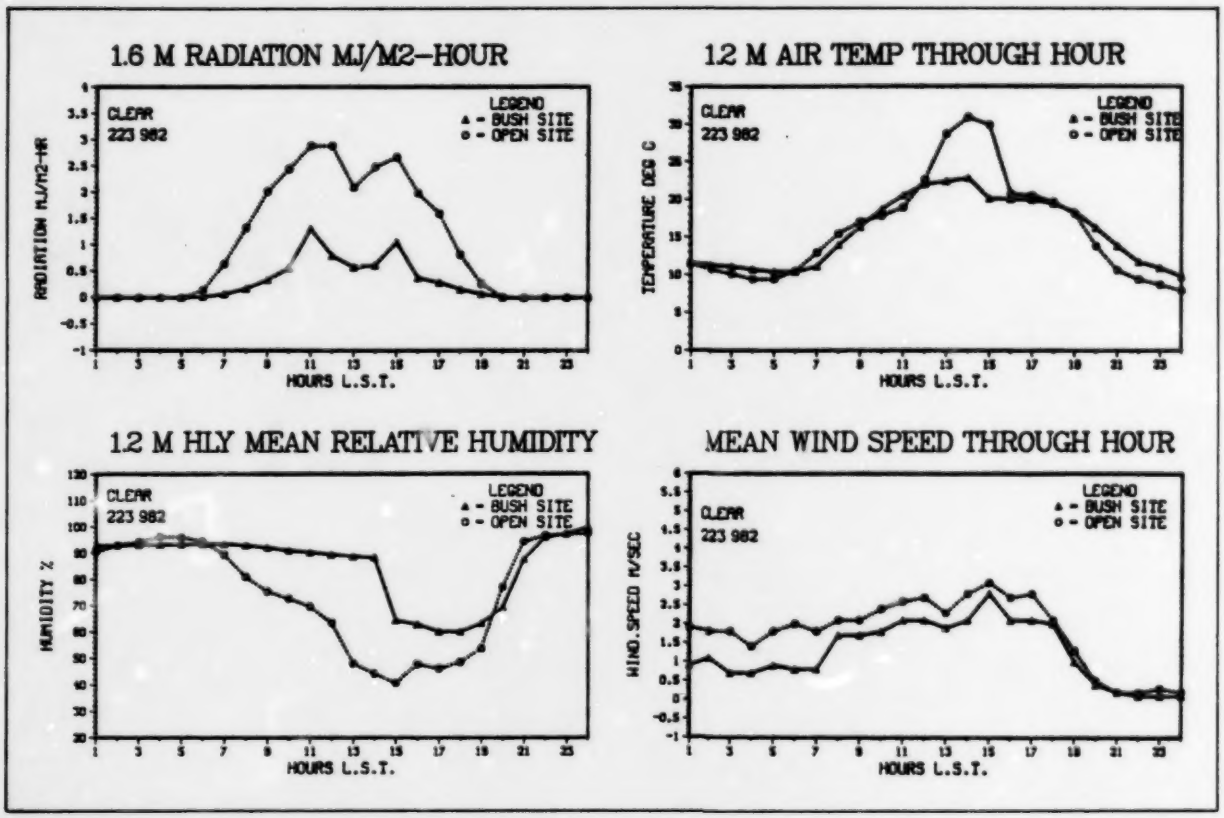
smooth. Again the relationships of the variables, radiation, temperature, relative humidity and wind were maintained. Maximum temperatures were 27.6°C in the bush and 29.3°C in the open. Minimum temperatures were 11.9°C in the bush and 11.0°C in the open.



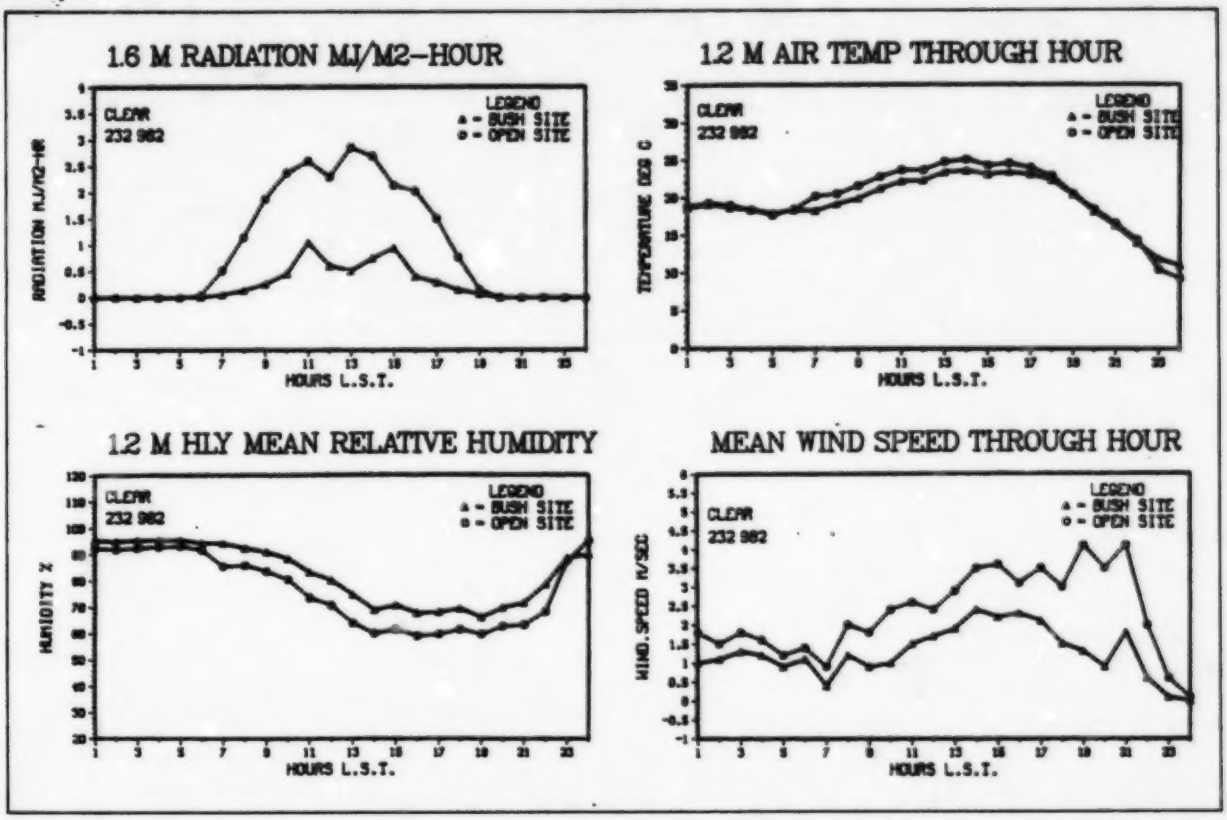
Clear Days

Day 223, August 11, 1982 was a typical clear day on the leading edge of a high. Formation of fair weather cumulus clouds reduced solar radiation for a short time around 1300. The 12Z map showed scattered to broken cloud with good visibility. In the bush the sharp peaks in the radiation curves at 1100 and 1500 would be partly caused by the alignment of the trees which would allow sunlight to directly reach the radiation sensor at these hours. Maximum temperatures rose to 24.5°C in the bush but reached 33.7°C at the open site in the sun around 1400. Between 1400 and 1500 relative humidities dropped rapidly to around 40% in the open and 60% in the bush with the rapid increase in temperature. Bush site relative humidities fell slowly compared to the open site's until this hour. After sunset the humidities climbed again to over 90%. Wind speeds were moderate during the day but diminished to near zero after sunset. Speeds were higher in the open than in the bush; however, the speeds were closer than on other days. With the high moving in the prevailing wind direction was west north-west. Physical barriers such as the hill and trees would be less effective in reducing wind speeds. A

decrease in convective activity in the evening along with the approaching centre of the high would account for the diminishing wind speeds.



Day 232, August 20, 1982 was a day with a colder air mass entering the area following the passage of a low which had moved out into Quebec. There was a strong northerly flow of air which kept wind speeds up until late evening and which lowered air temperatures particularly in the evening. The pattern for solar radiation was similar to that on August 11. The peaks at 1100 a.m. and 1500 p.m. in the bush were again evident. High temperatures were 24.6°C in the bush and 27.0°C in the open. The lows occurred in late evening other than at sunrise as usually is the case. Compared to day 223 the relative humidities on day 232 remained closer together between the bush and open sites. Wind would cause more mixing of the air and thus less local differences in humidity characteristics.



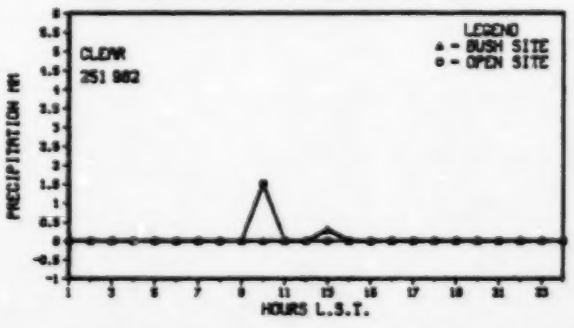
On Day 251, September 8, 1982 the weather was dominated by a large high pressure area. The precipitation graph shows that even on a bright sunny day there can be moisture recorded. At the open site 1.5 mm were measured during the hour ending 1000 a.m.; 0.3 mm were measured in the bush in the hour ending 1300 p.m. It is possible that the foliage received some moisture earlier in the day and that later some spilled into the bush site raingauge. Explaining these "precipitation" measurements leaves some room for speculation. There is a possibility that the "precipitation" may have been melting dew or frost which formed on the cold surface of the rain gauges in the early morning when the humidity was high, temperatures were low, and winds were light.

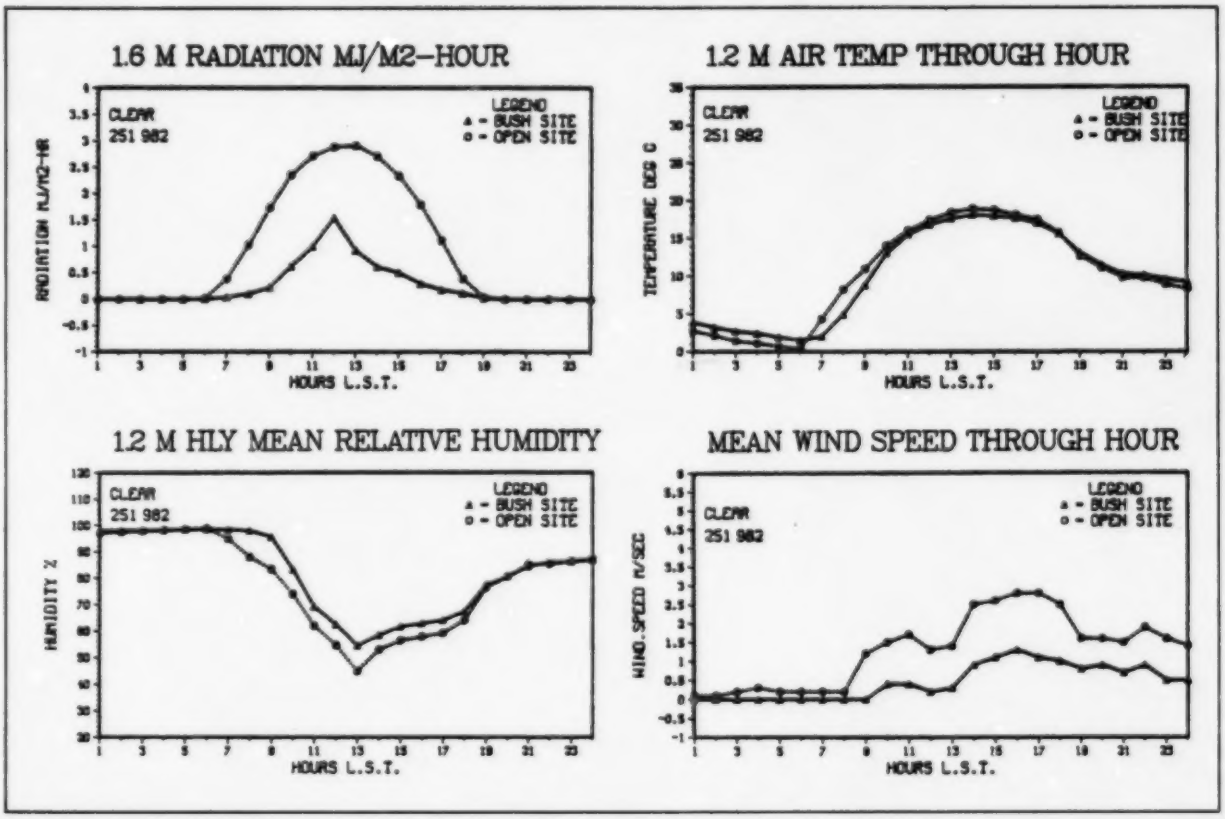
Rudolf Geiger in his text The Climate Near the Ground (1966) made references to studies by A. Made in May to July 1951, and A. Baumgartner in 1952. Baumgartner's study displayed dew profiles measured simultaneously in a young fir plantation and on bare ground. At the experimental station in the forest the maximum amounts of dew deposition measured on some nights reached approximately 0.3 mm at a height of between one and two metres. Dew deposition generally decreased above and below this level except in the crown area. "In open country maximum dewfall is located 1 to 2 m above the ground. This type of maximum was also found in Made's observations, on a dew recorder at a height of 50 cm above ground, showing 1.44 mm in October". Geiger (1966). These measurements do not appear far from those of the present study. The recording area of the tipping bucket rain gauges was at

about 50 cm. Weather conditions were conducive to the formation of a low level temperature inversion particularly at the open site. Treidl et al. (1978) found that on clear nights with light winds in spring the average maximum inversion strength between 0.3 m and 1.5 m was 2.51°C. This was in a young orchard near London Ontario. As the fruit trees developed this inversion strength lessened; however, this illustration shows that there can be considerably lower temperatures at the height of the precipitation gauges. The minimum temperature on September 8, 1982 was -0.2°C at the open site at 1.2 m. It is thus possible that dew or frost froze on the rain gauge and was not measured until after 9:00 a.m. when the ice would have melted. In the bush temperatures did not drop below freezing but some of the "precipitation" may have come from the foliage particularly after the wind speeds started to increase. Geiger (1966) states "Dew found within a stand, in spite of the insignificance in quantity, may become large on some nights when there has been a heavy deposit, since large drops of dew may drip through from twigs in the crown area and release a veritable cascade, a shower of dew." No precipitation was recorded at neighboring climate stations.

Some maintenance was performed on day 251, but this would not have been done until later in the day, and no work was indicated on the rain gauges. In the early morning the open temperature dropped to a low of -0.2°C at 0600 while in the bush the low was 1.1°C. After sunrise at both sites it rose until 1400 when the open site was 20.7°C and the bush 19.2°C. The curves for the sites crossed at sunrise and sunset. This demonstrates the moderating effect of the bush on temperatures. The next night was not as cold. Wind speed was higher on the night of September 8-9. On the night of September 7-8 it was almost calm. This would increase the chance of radiation frost. In the open at 1.2 metres the minimum temperature was -0.2°C. At the surface it dropped to 0.5°C. In the bush the minimum temperature at 1.2 metres was 1.1°C and at the surface 1.8°C. On the morning of September 9, the bush minimum temperature at 1.2 metres was 5.3°C and 6.0°C at the surfaces. Wind speed around sunrise in the bush on the 9th was about 0.6 metres per second and 1.7 metres per second in the open. On the 9th in the open at 1.2 metres the minimum temperature was 3.8°C and 4.4°C at the surface. Wind causes some mixing of the air which slows down cooling near the earth's surface. Relative humidities bore a strong inverse relationship to temperatures and solar radiation on September 8, 1982.

HOURLY PRECIPITATION IN MM





Representativity

In order to examine the relations of the observations at Codrington to the climate of the area, daily climate observations of maximum and minimum temperatures and precipitation were also gathered from neighboring climate stations. Some verbal descriptions of the weather were also included on climate observation forms from some of the stations. Those stations used for this purpose are Peterborough A, Peterborough Trent University, Peterborough S.T.P., Campbellford (precipitation only) and Smithfield C.D.A. Synoptic weather charts were also inspected for the period from mid-July to mid-October 1982. The following tables summarize these observations. For Tables 3 and 5 temperature statistics are presented only for the period of July 15 - October 11, 1982 as this was the period when air temperatures were recorded at both the bush and open sites. Precipitation statistics cover the period July 15, 1982 - July 31, 1983 in Tables 4 and 6. Days when comparable observations from both sites could not be obtained were omitted so as not to render the statistics invalid for comparison.

Table 3 presents means, standard deviations, and coefficients of variation expressed as a percentage of maximum and minimum daily temperatures. Table 4 has means, standard deviations, coefficients of variation expressed as a percentage, and sums over the study period of daily precipitation.

Table 3

Temperatures July 15 - October 11, 1982

All days	Maximum Temperatures				Minimum Temperatures			
	Mean	S.D.	C.V.	Days	Mean	S.D.	C.V.	Days
Bush Site	21.48	4.57	21.3	67	9.23	4.50	48.8	67
Open Site	22.72	5.04	22.2	67	8.26	4.60	55.6	67
Peterborough A	21.34	4.90	23.0	67	7.66	4.49	58.6	67
Peterborough STP	21.12	4.83	22.9	67	10.81	4.29	39.7	67
Trent University	21.46	4.99	23.3	67	10.15	4.53	44.6	67
Smithfield	20.59	4.63	22.5	67	10.53	4.36	41.4	67
Cloudy								
Bush Site	17.75	3.55	20.0	13	9.26	3.36	36.3	13
Open Site	18.49	3.98	21.5	13	8.91	3.86	43.4	13
Peterborough A	17.67	3.67	20.8	13	8.11	3.48	42.9	13
Peterborough STP	17.62	3.69	21.0	13	10.88	3.27	30.1	13
Trent University	18.00	3.91	21.7	13	9.77	3.18	32.5	13
Smithfield	17.15	3.16	18.5	13	10.50	3.16	30.1	13
Partly Cloudy								
Bush Site	21.63	3.86	17.9	22	10.47	4.40	42.1	22
Open Site	22.87	3.98	17.4	22	9.59	4.63	48.4	22
Peterborough A	21.57	4.21	19.5	22	8.83	3.99	45.2	22
Peterborough STP	21.20	4.23	20.0	22	11.80	3.77	32.0	22
Trent University	22.48	4.34	20.2	22	11.80	3.72	31.6	22
Smithfield	21.16	3.96	18.7	22	11.64	4.29	36.9	22
Clear								
Bush Site	22.89	4.66	20.3	32	8.37	4.87	58.2	32
Open Site	24.33	5.19	21.3	32	7.10	4.67	65.8	32
Peterborough A	22.68	5.13	22.6	32	6.68	5.04	75.5	32
Peterborough STP	22.50	5.01	22.3	32	10.09	4.91	48.6	32
Trent University	22.84	5.24	22.9	32	9.17	5.24	57.0	32
Smithfield	21.59	4.99	23.1	32	9.78	4.77	48.7	32

Table 4

Precipitation July 15, 1982 - July 31, 1983

All days	Precipitation mm/day				Season Total mm
	Mean	S.D.	C.V.	Days	
Bush Site	1.73	4.05	233.7	227	393.2
Open Site	1.69	4.02	237.4	227	384.0
Peterborough A	2.40	5.95	247.3	227	545.8
Peterborough STP	2.73	6.11	223.6	227	620.7
Trent University	2.53	5.66	223.9	227	573.9
Smithfield	2.22	5.02	225.8	227	504.3
Campbellford	2.37	4.72	199.0	227	538.5
Cloudy					
Bush Site	4.03	5.96	148.1	77	310.0
Open Site	3.85	5.95	154.4	77	296.6
Peterborough A	5.38	8.26	153.5	77	414.6
Peterborough STP	5.04	7.31	145.0	77	388.3
Trent University	4.98	6.92	138.9	77	383.6
Smithfield	4.24	6.60	155.8	77	326.3
Campbellford	4.96	5.95	120.0	77	381.9
Partly Cloudy					
Bush Site	0.83	1.86	223.9	57	47.4
Open Site	0.87	1.97	226.7	57	49.5
Peterborough A	1.07	4.43	414.2	57	61.0
Peterborough STP	0.98	2.09	211.9	57	56.1
Trent University	0.84	2.15	254.5	57	48.1
Smithfield	1.13	2.48	219.0	57	64.6
Campbellford	1.05	2.62	250.2	57	59.7
Clear					
Bush Site	0.19	0.80	420.0	85	16.1
Open Site	0.24	0.96	398.3	85	20.4
Peterborough A	0.60	2.36	396.4	85	50.7
Peterborough STP	1.57	5.32	338.9	85	133.5
Trent University	1.22	4.75	390.1	85	103.4
Smithfield	0.85	2.90	339.8	85	72.6
Campbellford	0.76	2.74	361.2	85	64.4

Table 5

Temperature Correlations July 15 - October 11, 1982

All days	Bush Site			Open Site		
	Correlation Tmax	Tmin	Days	Correlation Tmax	Tmin	Days
Bush Site	1.000	1.000	67	0.970	0.965	67
Open Site	0.970	0.965	67	1.000	1.000	67
Peterborough A	0.975	0.943	67	0.939	0.935	67
Peterborough STP	0.974	0.929	67	0.935	0.869	67
Trent University	0.967	0.896	67	0.932	0.848	67
Smithfield	0.961	0.879	67	0.932	0.822	67
Cloudy						
Bush Site	1.000	1.000	13	0.982	0.876	13
Open Site	0.982	0.876	13	1.000	1.000	13
Peterborough A	0.959	0.841	13	0.968	0.831	13
Peterborough STP	0.964	0.891	13	0.965	0.703	13
Trent University	0.914	0.898	13	0.942	0.761	13
Smithfield	0.935	0.751	13	0.963	0.597	13
Partly Cloudy						
Bush Site	1.000	1.000	22	0.988	0.977	22
Open Site	0.988	0.977	22	1.000	1.000	22
Peterborough A	0.969	0.956	22	0.967	0.945	22
Peterborough STP	0.977	0.933	22	0.975	0.888	22
Trent University	0.975	0.878	22	0.979	0.834	22
Smithfield	0.950	0.888	22	0.951	0.828	22
Clear						
Bush Site	1.000	1.000	32	0.950	0.983	32
Open Site	0.950	0.983	32	1.000	1.000	32
Peterborough A	0.975	0.955	32	0.905	0.957	32
Peterborough STP	0.969	0.934	32	0.894	0.902	32
Trent University	0.968	0.906	32	0.896	0.883	32
Smithfield	0.969	0.889	32	0.911	0.860	32

Table 6

Precipiation Correlations July 15 - October 11, 1982

All days	**Bush Site**		**Open Site**	
	Correlation Precipitation	**Days**	**Correlation Precipitation**	**Days**
Bush Site	1.000	227	0.973	227
Open Site	0.973	227	1.000	227
Peterborough A	0.582	227	0.567	227
Peterborough STP	0.435	227	0.435	227
Trent University	0.444	227	0.433	227
Smithfield	0.617	227	0.636	227
Campbellford	0.577	227	0.570	227
Cloudy				
Bush Site	1.000	78	0.976	78
Open Site	0.976	78	1.000	78
Peterborough A	0.561	78	0.555	78
Peterborough STP	0.502	78	0.506	78
Trent University	0.479	78	0.475	78
Smithfield	0.668	78	0.716	78
Campbellford	0.586	78	0.594	78
Partly Cloudy				
Bush Site	1.000	57	0.890	57
Open Site	0.890	57	1.000	57
Peterborough A	0.176	57	0.031	57
Peterborough STP	0.094	57	0.061	57
Trent University	0.100	57	0.037	57
Smithfield	0.206	57	0.126	57
Campbellford	0.319	57	0.183	57
Clear				
Bush Site	1.000	85	0.970	85
Open Site	0.970	85	1.000	85
Peterborough A	0.489	85	0.476	85
Peterborough STP	0.203	85	0.221	85
Trent University	0.119	85	0.106	85
Smithfield	0.556	85	0.507	85
Campbellford	0.281	85	0.343	85

Means can be used for comparison and extrapolation between sites or stations. If for example temperature observations are available for an open area or neighboring climate station, the temperature in a forested area can be predicted by applying a correction factor based on the difference between the means. Standard deviation is a measure of variability about the mean. In a normal distribution approximately 68% of cases should fall in the range of the mean plus or minus one standard deviation and 95% within plus or minus two standard deviations. Coefficients of variation are here expressed as the standard deviation divided by the mean then multiplied by 100. With precipitation this statistic can be used for a measure of variability within one station and in comparison with other stations. This can be done because the mean value used in its calculations is an absolute quantity which has a base of 0. When it is used with temperature which is a scalar quantity it does not have the same significance. For example, if the standard deviation of the temperatures were 4.5°C and the mean were 1.0°C the coefficient of variation would be 450 expressed as a percentage. If the mean temperature were 4.5°C then the coefficient of variation would be 100. However, the real variability would be the same as in the previous example. Also for precipitation the coefficient of variation remains the same whether the units are millimetres or inches while there is a change in the coefficient of variation with temperatures if Fahrenheit or Celsius scales are used. When temperatures are close between stations, this statistic can still be used as a measure of comparison of variability but caution should be used.

Table 5 is a table of r^2 (correlation coefficients) for maximum and minimum temperatures between the open site, the bush site, and neighboring climatological observing stations. Table 6 presents correlations for precipitation. The correlations give a measure of confidence in the relations between the data measured at the sites and the neighboring stations. If the correlation coefficient is near 1.0 a high degree of confidence can be placed in estimating the value of one member of a pair when the other member's value is known. If on the other hand, the correlation coefficient is near 0.0 no confidence can be put in such an extrapolation. Coefficients can be positive or negative. In the case of a negative correlation the value of one member of a pair would vary inversely with the value of the other member. If there is a high positive or negative correlation between sites, the value measured at one site can, with appropriate correction factors based on means, represent the values of one or more neighboring sites.

It can be seen that temperature correlation coefficients between the bush site and open site are high. Under cloudy and partly cloudy skies this relationship is slightly better for maximum temperatures than for minimum temperatures; however, under clear skies the correlation is better for minimum temperatures. In any case, most of the correlations are above 0.9. Thus it is possible with a high degree of accuracy to predict the temperature in the bush if the temperature in the open is known by adding an appropriate correction factor based on the difference between their mean values. Relationships with the surrounding climate stations are also good, but not usually as good as between the sites. Thus temperatures could be predicted with a fair degree of accuracy for the bush or open sites by knowing the

temperatures at these stations. In general during the day open site temperatures were higher than bush site temperatures and during the night open site temperatures dropped below those in the bush. Graphs as shown earlier in this paper can be used to predict temperature differences at specific hours between the sites. For daily maximum and minimum temperatures tabular values can easily be used as predictors or for comparison between stations or sites.

The mean values for all days revealed that there was little difference between the open site and bush site in mm per day of precipitation. The bush site mean was 1.73 mm while the open site mean was 1.69 mm. Under cloudy skies the bush mean was 4.03 mm/day while that of the open site was 3.85 mm. Under partly cloudy and clear skies the open site received slightly more with 0.87 and 0.24 mm compared to 0.83 and 0.19 mm at the bush site. From the amount of data collected it is still difficult to determine whether the forest has a significant effect on the amount of precipitation measured.

Because of its spatial and temporal variability precipitation is more difficult to extrapolate and interpolate than is temperature. Particularly in the summer months precipitation often comes in showers. Thus one area may receive a heavy shower while another not far away may receive almost none. Comparison of precipitation amounts over hours or even days can be difficult; however, over a longer period differences tend to even out. The closer the observations at two locations are together in time and in place, the more likely it is that the prediction of one site's precipitation will be accurate with reference to the other. Table 6 bears out these comments. Over all days the correlation between the open and bush site was high at .973. Smithfield had the best relationship of the climate stations with a coefficient of .617 with the bush and .636 with the open site. It was geographically the closest station. It also had a recording precipitation gauge. The times of observation would thus correspond more closely. Peterborough A also had a recording gauge and precipitation was measured for the standard climatological day; however, it is 44 km away to the northwest. Thus storm tracks would more likely be different over the two locations. Correlations with Peterborough A were .582 for the bush site and .567 for the open site. Campbellford had similar correlation coefficients; however, it is closer to Codrington at 15 km to the north. Precipitation measurements at Campbellford were only observed at 0700 and 1900. Thus precipitation may not have been recorded until the day after which it actually occurred. Peterborough Trent University and Peterborough S.T.P. had even lower coefficients for a combination of the above discussed reasons of distance and time of observations. Under cloudy skies correlations were better than under partly cloudy or clear skies. In the latter cases precipitation would more likely be in the form of scattered showers while under cloudy skies precipitation would be more extensive.

From the above it may be concluded that precipitation amounts may be extrapolated only with caution. Because of the greater spatial and temporal variability of precipitation more stations particularly with recording

gauges which record both times and amounts of precipitation are required to estimate the times and amounts of precipitation at a given site.

Summary and Concluding Comments

In the introduction it was pointed out that needs of foresters and farmers for climate information differ significantly from those of the aviation industry. This paper has compared and contrasted the climate as found in an I45/51 hybrid poplar farmed forest environment with the climate of a nearby open level field which is more typical of airports and standard climate stations. Comparisons were also made with established climate stations in the area. Some statistical data have been gathered which describe the climatic characteristics as found in both these environments. There is still a need for refinement of procedures and instrumentation however. Also a longer study period over a number of years would have provided better statistics. This will have to be left to a future study. In spite of the limitations, the methodology used in this study has shown that data as collected at airports and climatological stations can be applied to this type of forest environment with appropriate adjustments; however, the ability to accurately estimate precipitation data in the forest environment diminishes much more rapidly than for temperature with distance from the climate stations. Thus the lack of climatic information available in the forest environment can at least be reduced.

Some practical experience in performing such a study was gained. Most of the instrumentation and recorders employed in this study were 'automated'. It must be stated that such meteorological instruments and recorders still require frequent attention to continue to function properly, particularly in the bush where leaves, branches, and debris can interfere with anemometers and precipitation gauges. Tower mounted sensors, especially those for solar and net radiation are attractive to birds and small animals. Net radiation was not discussed in this paper (although it was sometimes recorded) because too many days' observations were lost due to damage by birds. Power supply is a major concern. An AC power line was run into the open site. The CR21 datalogger at this location was able to be plugged into this power source with an adaptor. On the other hand at the bush and hill sites battery DC power had to be used. A number of observations particularly at the latter two sites were lost due to battery discharge or else in changing batteries. Description of the hill site climate was not included because too many observations were lost. A design improvement to the dataloggers to enable easy transfer of power from an alternate DC source during battery replacement as well as an easily accessible battery compartment such as found in many cameras would substantially reduce the number of lost observations. In most such field studies battery power is necessary because of their remote locations and for economic reasons.

The data collected and the statistics generated in this study quantify and confirm statements made by Johnson et al (1971) and Geiger (1961,1966). Numerical data have been provided in this paper which can be put to practical use to determine how much meteorological parameters are affected by a forest environment. It has been demonstrated that incoming solar radiation

is reduced in the bush compared to open areas and that the difference in radiation received is inversely proportional to the amount of cloud cover ie. on cloudy days there is not as much difference in the amount of radiation measured in the bush and in the open as there is on a sunny day. It also has been shown that the intensity and temporal distribution of radiation measured near the forest floor can be affected by the arrangement of the forest canopy. This is most evident in a plantation where trees are aligned in rows. Particularly, examples from this analysis are depicted as peaks in the bush radiation graphs at 11:00 am. and or 3:00 pm. in figure 3 and on days 223, 225, 232, 240, 255, and 282 when the sky was partly cloudy or clear. In the open, radiation curves were usually smoother with maximum amounts measured around noon to 1:00 pm. Terrestrial radiation is retained more in the bush and under cloudy skies.

Temperature varies directly with the amount of radiation received and absorbed. Thus open areas are warmer during the day than are bush areas, and conversely at night, bush areas are warmer. Relative humidity usually varies inversely with temperature and radiation. Warm air normally has a higher holding capacity for water vapour. Thus if there is an increase in temperature without an increase in the amount of water vapour, the relative humidity diminishes. This characteristic is accentuated in the open particularly on partly cloudy and clear days. Most of the daytime relative humidities were lower in the open than in the bush. In part this would be due to the greater amount of solar radiation received in the open than at the forest floor. The rate of decrease in relative humidity is also lower in the bush (particularly in the morning hours) than in the open. Open site relative humidities start to drop fairly rapidly after sunrise on clear days. In addition to lower amounts of radiation being received in the bush due to shading, evaporation would also be reduced as a result of lower temperatures and wind speeds. Thus more moisture would also be retained in the bush. Advection of more moist air or increased transpiration can increase the amount of water vapour. On day 223 the humidity remained fairly high in the bush at near 90% until early afternoon. By this time the humidity at the open site had dropped to less than 50%. With the high temperatures of the day there would have also been a rise in the rate of evapotranspiration particularly in the bush where trees can draw up water from deeper in the soil. On cloudy days or when weather systems move in there is little difference in the humidity patterns of the bush and open sites as the humidity at both sites is more characteristic of the air that is advected into the area than of an air mass which develops within the area. Thus a rise in temperature does not always result in a drop in relative humidity.

Wind speeds are normally reduced in the bush compared to open areas. Also the alignment of trees and physical barriers can change wind directions or cause channelling. Figures 15 through 17 depict hours of wind measured from sixteen directions at both the bush and open sites under cloudy, partly cloudy, and clear sky conditions. In all diagrams fewer hours of wind were measured from the south, south-southwest, and southwest at the bush site than at the open site. Also there were more hours of wind from the west-southwest and west at the bush site. These figures illustrate the steering

effects of the physical features and the tree alignment. These figures also illustrate a change in circulation patterns under different sky conditions. Cloudy skies are more likely to occur under cyclonic patterns. This often results in more wind from the north-east quadrant. Thus it can be seen that more winds are measured from the north-east on cloudy days. The influence of surface roughness can also affect the wind directions. On cloudy days winds with a more northerly component were more common at the open site than at the bush site. Winds would tend to decrease and be steered when encountering the trees.

From the amount of precipitation data gathered in this study it is difficult to determine whether there is any significant difference in the amounts of precipitation received in open and forested areas. In this sample of days when observations were complete at both experimental sites, on cloudy days an average 0.18 mm more precipitation was measured at the bush site than at the open site. On days classified as partly cloudy or clear about .04 mm more was measured at the open site. Overall the mean daily precipitation measured at the bush site was 1.73 mm and at the open site 1.69 mm. Standard deviations were high reflecting a high degree of variability in the amount of precipitation received at both experimental sites. Depending on the nature of the precipitation there may be more or less precipitation measured at the bush site compared to the open site. There may also be a difference in the time or duration of measurement. This has been seen on several individual day cases. Examples can be found on days 225, 240, 251, and 267 in 1982. The peak in the bush precipitation at 1800 L.S.T. on day 267 was probably due to a local heavy shower. The open site rain gauge was relatively free of any obstructions. Thus showery precipitation would more likely to be measured when it actually occurred in the open than in the bush. In some showers it was seen that more precipitation was measured at an hour in the open than in the bush; however, some precipitation was measured the next hour or two in the bush when the open site gauge indicated that precipitation had already ended.

The forest is a more sheltered environment. Thus in almost all cases with all parameters, changes take place more slowly and are less intense in the forested area than in open area.

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